WAR DEPARTMENT
OFFICE OF THE CHIEF SIGNAL OFFICER

RPLANE MOTORS

A COURSE OF PRACTICAL INSTRUCTION IN THEIR CARE AND OVERHAULING

FOR THE USE OF

MILITARY AVIATORS

BY

GEORGE E. A. HALLETT, A. M. E.: A. S., S. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
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WAR DEPARTMENT,
OFFICE OF THE CHIEF OF STAFF,
Washington, January 10, 1918.

The following Instructions on Airplane Motors, a Course of Practical Instruction in Their Care and Overhauling for the use of Military Aviators, by George E. A. Hallett, A. M. E., A. S., S. C., prepared in the office of the Chief Signal Officer, is approved and published for the information and guidance of the Regular Army and the Organized Militia of the United States.

BY ORDER OF THE SECRETARY OF WAR:

JOHN BIDDLE,
Major General, Acting Chief of Staff.

A PRACTICAL COURSE OF INSTRUCTION IN THE PRINCIPLES, OVERHAULING, AND CARE OF AIRPLANE MOTORS.

By Geo. E. A. Hallett, A. M. E., *Signal Corps, Aviation School, San Diego, Cal.*

INTRODUCTION.

Object of this Course.—In the case of student flyers, it is to give them a practical knowledge of airplane motors sufficient to enable them to diagnose motor trouble when on cross-country flights and to make rapid and practical repairs if possible, or, in any event, to be able to send an intelligent message for parts, etc., and to explain to mechanicians nature of trouble and its remedy.

In the case of the mechanician, the object will be to make an airplane motor man out of an automobile mechanic or machinist. Parts of it should be useful to give to automobile factories to help them train aviation mechanicians. *The course consists of:* (1) A series of lectures, beginning with principles and covering a wide range of practical work as well as bench and block work. (2) A bench course, of overhauling unserviceable motors (preferably airplane motors; methods explained later). (3) Block course of installing motor on a test block or in a fuselage; placing propeller, cranking, handling switch and throttle to start motor, carburetor adjustment, "trouble-shooting," emergency repairs, inspection or "prevention of trouble." (4) If time permits, a study course in some good gas-engine book.

Attached will be found a list of twenty assignments in "Dyke's Automobile and Gasoline Engine Encyclopedia." These assignments cover the automobile chassis in addition to motors, and will be found fairly satisfactory. While this book has many typographical errors, it is fairly practical.

Methods of Conducting Practical Motor Course.

The course should last from four to six weeks (18 hours per week), according to the amount of material or motors available.

Three men on a motor is an ideal number. If more are put on one motor, the work progresses too fast and therefore does not "soak in." It will be possible to give a ten-day course, all day sessions, which will cover all the work. (NOTE.—Each three men are called a "section.")

Always encourage the asking of questions.

The First Few Days.

The first lecture should be given on the first day. Other lectures should be given as the work progresses. The first thing to do is to spread out all the tools on the benches and name them, so that all will know them by the same names. Give each section a *simple* motor. (NOTE.—This motor can be quite obsolete, and not necessarily complete.)

Explain principles of disassembling motor as the work progresses.

1. Find the number on the parts.
2. Decide in which order parts should be removed. (NOTE.—Some parts are not accessible until others are removed.)
3. Show best methods of removing cotter pins.
4. Make marks on timing gears before disassembling.
5. Keep shims and liners in proper place (explain importance).
6. Cleaning parts (especially oil passages).
7. Nomenclature of parts.

Assembling.

Explain as follows:

All parts must be carefully oiled, because the oil pump and oil pipes are now empty, and it will be best to keep the idea in mind that an engine may run as much as ten minutes before the pump can deliver oil to all the parts.

Bearing nuts must be tight. Never loosen the nuts to loosen the bearing, but add shims or scrape it out if it is too tight.

Explain the following:

Making paper gaskets.

The use of shellac and graphite with these gaskets.

Grinding valves. (NOTE.—Grind by hand and lift off the seat between *each* stroke.)

Test the valves with gasoline.

How to distinguish the exhaust valves from inlet valves. (NOTE.—The exhaust valve stems will be darkened by heat; sometimes the heads are designed differently. Exhaust valve springs are always the strongest if there is any difference in the two springs.)

Valves should never be ground more than necessary. If there is a fair width of seat all around, it is better to leave a few "pits" near the edges rather than to grind so much of the valve seating away.

Explain valve timing in its simplest form, viz, put the gears together by their marks. (NOTE.—It is not necessary to put an ignition system on this engine.)

Have the class trace the water circulation and oil circulation.

Explain how to determine the direction of rotation of the motor by watching the valves, as follows:

We know from the lecture on the first day what must occur inside a motor to make it run. Remember that after the exhaust stroke (recognized by the exhaust valve being open) we have a suction stroke (which we recognize by the opening of the inlet valve). Therefore when we turn the motor in the proper direction the inlet valve will open *immediately after* the exhaust valve closes.

The above work will consume a different length of time with different classes and motors, and therefore I set no definite time for its completion.

When this work is done, give the class motors which are complete and more modern, preferably airplane motors.

It is an immense advantage if the motor can be installed on a testing block or in a fuselage of an airplane and run on completion of overhauling, because the class will show far more interest and effort under these circumstances.

As the sections begin work on these motors, make them observe all the precautions taught on the first motors, and also teach them how to measure and find the valve timing (closing position of exhaust valve) either in degrees or piston position. In airplane motors the valves are usually timed by piston position.

Explain that this is a motor which is new to us, and we must know the valve timing in order to be able to put it together properly. While it is true that ordinarily we could time the valves by the marks on the timing gears, remember that frequently parts either of the gears, the crank shaft, or cam shaft must be replaced, and as keyways and gear teeth are not cut so that these parts are interchangeable our marks will be of no value. Therefore we must know other methods of timing the motor. We will time this motor by degrees, preferably by piston position, as we assemble it, and must know the valve timing.

Explain measuring spark timing. (Find at what piston position the spark occurs.)

Explain how to try the bearings for looseness before the motor is disassembled, so that we will know how many shims to remove before assembling them. This saves time, because if it is not done it will be necessary to assemble the bearings before deciding how many shims to remove.

Explain that they must note the gear clearance between the crank shaft and the cam shaft, so they will know if the bearings must be raised, or possibly renewed, before scraping them.

Try the adjustment of the thrust bearings and oil-pump gears before disassembling for the same reasons. The thrust bearing of an airplane motor must hold the crank shaft so that it "floats" between the main bearings. The cheeks of the shaft must not be able to touch the cheeks of the bearings.

In adjusting a thrust bearing, if there is, for example, a 3/64th of an inch end play in the crank shaft, the thrust bearing should be so adjusted that it will hold the shaft so that 2/64 of that clearance will be on the side which will be reduced by wear in the thrust bearing. Then if the motor is a tractor, the greatest amount of clearance should be left on the side of the crank throw which is toward the thrust bearing, because the pull of the propeller will wear the thrust bearing in that direction.

Explain the testing of the crank shaft, or, if possible, test the crank shaft by placing it in a lathe, between centers, and by using a gauge to determine to what extent the crank shaft is crooked. Explain that crank shafts are not used if they are more than 5/1000 of an inch out of line or crooked, but must be straightened or reground.

Then carefully measure the journals with a micrometer. The journal must not be over 5/10000 of an inch out of round. Crank shafts become crystallized in time, even in comparatively heavy engines. For instance, the big omnibus companies of London set a specified number of miles that a crank shaft of any certain make is allowed to be used, because it is found through long practice that if used longer than this the crank shafts are liable to become crystallized and wreck an entire motor when they break. At present, in this country, limits are being put on the use of certain makes of crank shafts in airplane motors. For example, one crank shaft used in the service must not be used more than three hundred hours of flying time.

Explain the alignment of the main bearings. Emphasize the fact that the crank shaft is limber, and if we should bear down on it while marking the bearings, it might be possible to mark a bearing which was already 2/1000 of an inch low, etc.

The scraping of bearings should be taught, because it is necessary to scrape bearings in overhauling a motor, even though they are usually reamed when the motor is built. If possible, give the students some old bearing caps to practice scraping on. Instruct them in the use of the scraper; warn them to avoid starting or stopping a stroke abruptly with the scraper, because this leaves little notches which the scraper will jump over on the next cut. After cutting a series of parallel strokes to cut away part of a bearing, the scraper should be moved across the surface diagonally to smooth it up. Point out that it is necessary to cut comparatively lightly on the sides of the bearings. For example, if you are letting the shaft down into a bearing 1/1000 of an inch, it will be necessary to cut a thousandth deep at the bottom of the bearing, but as the shaft is not going to be moved horizontally we will not cut any metal away at the top of the sides, and only one-half a thousandth half way up the sides. In other words, cut deepest in the bottom of the bearing and lighter and lighter as we work up the sides. The oil circulation of the motor should be systematically traced and all oil passages and screens carefully cleaned.

Cutting Oil Grooves.

If the bearings are renewed in a motor, the oil grooves in the new bearings should be cut in exactly the same manner that they were cut in the old ones. The form and location of oil grooves are usually experimented with in the motor factories and should not be altered by the mechanic who does the overhauling.

Adjusting Bearings.

Before deciding how tightly our bearings should be adjusted we must consider these things: Have we a low-pressure lubricating system, high-pressure lubricating system, worn bearings (bearings worn smooth), or newly scraped bearings? The modern idea of bearings in an airplane motor is to fit them loosely, from two to four thousandths of an inch, and maintaining the oil film by forcing a large amount of oil through the bearings under very high pressure. If we have a high-pressure lubricating system, the bearings can be and should be fitted loosely. For example, they should be carefully scraped and fitted to the shaft and then a two-thousandth shim placed in each side of the bearing to loosen it up. If we have a comparatively low-pressure lubrication system, the bearings must be adjusted closer, or they would hammer out. If we have newly scraped bearings, the shaft will touch the bearings only in comparatively small spots. These spots wear rather fast, so the bearing loosens up quickly for a short time, until the shaft has worn the bearing to a perfect " fit." Knowing this, we adjust newly scraped bearings tighter than we would if we were simply adjusting bearings which we already worn smooth.

Instruction in filing should be given at this stage as it is frequently necessary to adjust bearings by filing the bearing cap. Impress the fact that nuts on all bearings must be very tight. Point out that on a "V" type motor, and also on the vertical type, if the bearing cap is not pulled down very tightly it will shift or "work" while the engine is running, and it is only a matter of time until the main bearing studs will be crystallized and broken.

When fitting new connecting rods or newly babbitted connecting rods to a crank shaft, it is necessary to test them for alignment. One method is to put a bar through the wrist pin end of the rod, set the rod up on the crank shaft and measure from the main journal on either side up to the ends of this bar, to find out whether the connecting rod stands exactly perpendicular to the crank shaft. (Old connecting rods can be used for this purpose.)

Disassembling and Reassembling Piston Pin Bearings.

Explain methods of avoiding the straining or distorting of the pistons and also the necessity for these precautions.

Most of our modern motors use the aluminum alloy piston. Due to the expansion of the pistons when hot, the wrist pins must fit tightly while the pistons are cold. And as we do not wish to distort the piston by forcing the wrist pin into it, we sometimes heat the piston in hot oil or water and then *drop* the wrist pin in, thus avoiding some chances of distorting the piston.

The piston rings should be removed and replaced. Explain methods and precautions. Explain that the lower edge of the piston ring and the lower edge of the ring slot are as important as the face of the ring; because the rings must be free in the slots and therefore the pressure and the hot gases will get in behind the rings, and unless the lower edge is perfect, will get out *under* the rings. In this way rings are made practically useless. Rings must be returned to their own slot in the same position as they were before (same side up).

Explain fitting of piston rings and particularly the adjusting of the gap in the ring to allow for expansion. Rings must not be stretched or twisted.

Grinding and Testing the Valves.

Most mechanics have a tendency to grind valves to excess. It is best to grind them as little as possible. In other words, if the valve is badly pitted do not try to remove all the pits, but grind until you have a good width of seat all the way around the valve.

The valve springs should be tested while compressing them to the length which they occupy while on the cylinder with the valve seated. Find out what their tension is by weighing them on a spring scale.

Oil up the cylinder and pistons before assembling. Be sure to explain that rags must never be used for this purpose. Use only the bare hand which can be easily freed from all grit, and while oiling with our hands we can detect grit if present. Oil the piston thoroughly, under the rings, in the wrist pin and all over the outside. Oil the cylinder all over the inside; leave no dry spots. Explain precautions in slipping the cylinder over the pistons. If a ring is broken, it will score the cylinder. See that the cylinder gasket is not doubled over on one corner, because there is danger of throwing the cylinder out of line in this way. When engines have separate cylinders, it is necessary to line them up carefully with a straight-edge so that the inlet manifold will not have to be sprung, and be under strain when bolted to the cylinders. It is usual to test the manifolds after assembling by blowing into them by mouth or with air pressure; then put oil on all the joints and see if bubbles come through.

The water pump stuffing boxes should be carefully packed. Explain the importance of polishing the shaft before packing to prevent excessive wear on the packing.

Explain the necessity of putting in the largest possible amount of packing, because the more packing you can get into the stuffing boxes the looser it can be left without leaking and less wear and less friction will result.

Explain that the stuffing boxes should never be allowed to leak, because if they do, the shaft will rust, become rough, and cut out the packing.

Assemble the valve-operating gear. In high-speed motors it is very essential to have every part of the valve-operating mechanism working perfectly freely. Adjust the valve clearance. (See Lecture No. III.) . Time the cam shift. (See Lecture No. III.) Time the magneto and wire up. (See Lecture No. V.)

Be sure to have every man in the class go through these processes by himself and be sure he understands it. Never allow them to call the process complete without checking it afterwards to find out exactly what results they have obtained. This is important, even with the best mechanics in airplane work. Always preach the idea of preventing trouble where possible.

All the way through the process of assembling a motor bear in mind the necessity of having an oil supply for all moving parts run for the first few minutes before the oil pump can fill all the passages and deliver oil to all parts.

If possible, these motors which we are just finishing overhauling should be installed on a testing block or in a fuselage, and run. Then, if time and material permit, widely different types should be overhauled.

Block Work.

Actual power determinations are of comparatively small practical value to an airplane mechanic, but the motor can be run with a propeller or a club. While installing the motor impress upon the class that the switch and ground wire must be connected before the propeller is put on. In this way the motor can be made safe while the propeller is on, thereby lessening the danger of some one being kicked. On many engines it is necessary to place the propeller in relation to the spark timing, so that the propeller will come in a position which is convenient for a strong pull while the magneto is in a certain position. In case it should be necessary to explain this, it can be done as follows:

Place the propeller on the engine, but without fastening, so that it can be swung freely without revolving the engine. Now stand in the proper position to crank the propeller and hold the blade in the position where it will be convenient to start the pull. Note this position. We must have room to pick up speed before the spark occurs, to avoid back kicks. Therefore move the propeller down about twenty degrees and note this position. This is where we wish the "break" or spark to occur. Next attach the propeller lightly, so the motor can be turned over. Open the breaker box on the magneto, turn the propeller until a break occurs (it doesn't matter in which cylinder). Now disengage the propeller; put it in the position where we said we wished the spark to occur; secure it in the proper manner. This simply brings the explosion in the proper position for cranking.

Precaution.

In most magnetos, when the breaker cover is removed, the switch no longer short circuits the magneto; therefore, while performing this operation of placing the propeller, it will be wise to remove the connection between the collector brush and the distributor. Or if this is not accessible, remove the wires from the distributor or from the spark plugs, because there may be enough gasoline fumes in the cylinder to cause an explosion and a "kick."

Propeller Notes.

Never rock the propeller as a preparation to the final pull for starting. Many people are hurt in this way. Place your propeller where you intend to start the pull, rise up on tip toes, and start your pull strongly. Remember you must pick up a great deal of speed in the first few degrees in order to "carry over" the spark. As you finish the pull or stroke, manage so that you will be withdrawing your hands. If the motor kicks back, never try to resist it; simply withdraw your hands instantly. Never have tools in your pockets while cranking. They may fly out of your pockets and be "batted" through your legs by the propeller.

The man at the propeller and the man at the switch should "sound off" what they are doing, *so there may be no misunderstanding.* Make it a rule that the man at the switch will not say "closed" until the switch *is* closed, because if he should say "closed" and then leisurely reach over to close the switch or make the motor safe, the man at the propeller might work faster and pull the propeller, believing the engine to be safe, and get a severe kick.

It is very important to have the throttle closed or nearly closed whenever the switch is open. On the testing block, cranking the motor with the throttle open to start it will only result in the motor starting violently and a possibility of injuring the man cranking; but in an airplane the danger is greater, because the machine is likely to start ahead and *seriously* injure the man cranking the propeller, as he would not be able to get out of the way.

After installing the motor, make the class inspect the water, oil, and gas supply and also the ground wire and switch. Start the motor and run it slowly at first. Point out that the motor must be warmed up slowly and gradually to avoid unequal expansion and consequent cracking of parts.

Carburetor Adjustment on the Block.

This work is particularly valuable in training the pupil's ear. The Model "L" Schebler carburetor is suitable for this work, because it is adjustable yet simple. To make the adjustment of the carburetor as simple as possible, adjust the auxiliary air valve spring so that it just holds the valve against the seat, before starting the motor. This leaves only the gasoline adjustments to be made.

Then emphasize the fact that the looser the auxiliary air valve spring is left, the larger volume of air will pass through the inlet pipes to the cylinders, giving full charges of gas to the cylinders and therefore more speed. The limit to this is, that if the air valve is too loose the motor will not be able to get enough gasoline even with the gasoline adjustments wide open and also the motor will be liable to stop when throttled down, and "pick up" badly.

Have every student go through this work himself, if gasoline and time are available. Teach them that they must learn to make the adjustments quickly to avoid overheating of the motor in airplane work. Then disarrange the adjustments after each student finishes.

It is well to use open exhausts (no muffler) for this work, so the class will become used to the noise and also the appearance of the exhaust under the various mixtures and conditions.

Diagnosis of Trouble.

This is a very practical subject and can be so taught that it will be very valuable not only to the mechanic but also the pilot. The work consists of artificially causing troubles which really do occur in practice on the field, then having the class find the troubles. It is necessary to have the motor, preferably an airplane moter, mounted on a block where it can be run. The instructor should plan the troubles carefully, simple ones at first, and plan so there will not be two troubles giving the same symptoms at the same time.

To get the real value out of this work, first give Lecture No. VIII on system for diagnosis of trouble. Do not let the class go ahead and find troubles by inspection and haphazard methods, but make them *reason out* where the trouble is and why. If necessary reason out loud for them. Never make troubles by changing carburetor adjustments and never allow the class to correct troubles by changing these adjustments. By following this rule, you will help to combat a failing of the human race, viz. to try to correct all troubles by adjusting the carburetor.

The following are some of the troubles we make on the Curtiss 8-cylinder engines. They may serve as a suggestion for this work.

Ignition Troubles.

A Bosch magneto type DR8 is suitable for this work.

Bad plug.
Shorted spark plug.
Loosened spark plug gasket.
Spark plug wire off.
Spark plug wire shorted against motor.
Ground wire short-circuited.
Magneto leads crossed.
Magneto leads disconnected.

Magneto brushes missing. (Collector brush, bridge brush, ground brush, and distributor brush.)

Broken insulation at spark.

Dirt in breaker.

Various breaker troubles. (Points of breaker apart; out of adjustment and breaker screw loose.)

Magneto firing on the wrong stroke.

Safety gap shorted.

Breaker timed wrong. (Off the key.)

Water in magneto.

Various shorts in the secondary. For example, drill a small hole in the distributor arm to the middle of the core in the center; insert a small wire in this hole and cover over the surface.

Magneto fully retarded and key removed from driving gear so magneto will shift out of time.

Magneto timed on wrong top center.

Carburetor Troubles.

(Note.—Schebler Model "L" is suitable for this work.)

Remove the auxiliary air-valve spring. Block the auxiliary air valve open (with short piece of copper tubing).

Remove float valve.

Partially obstruct float valve.

Obstruct spray nozzle, partially and completely.

Loosen joint in the inlet manifold.

Put bad gaskets in the inlet manifold joints. (Gaskets which will cause a leak.)

Put water in the float valve of your carburetor.

Cause the float to stick.

Replace the lift-lever spring with a weaker one, so that the roller will not follow the cam.

Plug the air vent in the gas tank.

Valve Troubles.

No clearance, or valve held open.

Cam follower stuck (no lock washer on set screw).

Defective push rod.

Cam shaft gears meshed wrong.

Weak exhaust valve springs.

Cut the points off the cam-follower-guide set screw, so it will allow the cam follower to turn.

Piece of wire holding valve off seat.

Cam follower turned around.

Water in the cylinder. Fill your cylinder full of water while the piston is at the bottom of the compression stroke, and if the water gets in several of the cylinders on the same side, have the class blow the water out by removing the spark plugs on that side of the motor and running the motor on the other four cylinders. This is an effective way of removing water from the cylinders.

Inspection for Prevention of Trouble.

The instructor should loosen up and disarrange numerous parts of the motor, propeller fastenings, gas feed, cooling and lubrication systems, making note of all he does. Then call the class out and explain that they are supposed to fly over two hundred miles of rocky mountains with this motor to-day and it will be necessary *to inspect with the idea of preventing trouble*, and make note of all they find wrong. When they are through compare the notes and tell the class whether or not they can theoretically fly safely across the mountains; then have them start and run the motor.

Emergency Repairs.

Remove suitable parts of the motor, magneto, or carburetor and have the class make emergency repairs with iron wire and tape.

Have each section select tools and supplies which they consider most necessary to take along in an airplane on a long trip. For example, tape, assorted nuts, cotters, etc., soft wire, spark plugs, exhaust valve springs. Distribute the tools so there will be a wrench for every part of the motor, but no excess wrenches; try to find one wrench which will answer many purposes. Explain that the most serious work necessary to prepare for would be the removal of one cylinder.

TEN PRACTICAL LECTURES ON AIRPLANE MOTORS.

(NOTE.—The lecture room should be equipped with blackboards, and lectures should be illustrated by diagrams on these boards. Also a "cut-away" model of a four-cycle motor, showing all moving parts, magnetos, carburetors, any small parts which might help to illustrate the lectures.)

LECTURE I.

Subjects.—Principle of four-stroke cycle engine, heat loss, and reasons for cooling.

(NOTE.—Nomenclature of parts should be taught about this time on the model.)

It is of vital importance thoroughly to understand the elementary principles of the motor, because once they are mastered we can reason out the solution of many motor difficulties.

1. First, let us consider the burning of city gas in the open, unconfined. If we light the gas as it flows out of a gas jet, it burns with a small amount of heat and without generating any pressure, and with no noise. Now, if we take a pipe several feet long, closed at one end, and put in enough gas to fill it for six or eight inches, and then ignite the gas, it will burn and rush violently out of the open end of the pipe. If we should take the same amount of gas and place a plug in the pipe, the plug will be forced out along the pipe for a certain distance. Now, with the same amount of gas, if we force the plug down, compress the gas into one-third of its original space, and then ignite it, we find the plug will be driven much farther and much faster than before.

2. In the first gas engines made, gas was drawn into the cylinders and burned without being compressed. The result was it required a great deal of gas to develop a given amount of horsepower. In other words, the engines were very uneconomical. Later it was found that by compressing the gas before firing they were able to obtain a great deal more power with the same amount of fuel. When gas is compressed it will burn much more rapidly. Naturally, in a motor running at the speed that our airplane motors do, gas must be burned completely in a very short space of time in order to do any work. Now, we can understand that for a motor to run it will be necessary, first, to draw gas into the cylinder; then the gas must be compressed; then it must be burned and expanded and the burned gas cleared out of the cylinder. These four things must be done in any gasoline engine.

Four-Cycle Engine.

3. Practically all engines now used in airplanes are of four-cycle, or more correctly speaking, four-stroke, cycle type. This word cycle practically means a "program." The complete "program" of events occurring in these engines could be said to be composed of four "acts" or events. These four events are suction, compression, expansion, and exhaust. Each event requires one movement or stroke of the piston to complete it. The first stroke will be an outward stroke of the piston, drawing gas into the cylinder. This we will call the suction stroke. The next stroke will be an inward stroke of the piston, compressing the gas in the cylinder. That is the compression stroke. Then the gas will be ignited, and as it burns it will expand and drive the piston outward. This is the working or expansion stroke. The fourth stroke is an inward stroke of the piston. A valve will be opened and the piston will force out all the remaining hot air and smoke left from the explosion, thus leaving the cylinder clean for a new charge. This is the exhaust stroke.

Thus we see that we have one working stroke and then three idle strokes before the next working stroke. If our engine has only one cylinder it will be necessary to have a large flywheel which will be capable of storing up energy during the one working stroke sufficient to carry the piston through the three idle strokes. In an engine with more than one cylinder the other cylinders can take the place of the flywheel. To sum up: The four-cycle motor requires four strokes to complete the cycle. These strokes are first, suction; second, compression; third, expansion or working stroke; and fourth, scavenging or exhaust stroke.

4. When we compress air it becomes heated if we compress it rapidly enough. For instance, if we are pumping an automobile tire the pump becomes warm. This is not entirely due to the friction of the plunger in the pump, but partly due to the work of compressing the air. The same is due when we compress gas or a mixture of gasoline and air in an engine cylinder. As we compress gas in the cylinder it is heated to a certain extent. Then we have the heat of the electric spark which we use for igniting the gas. The heat of the electric spark together with the heat of the compression is sufficient to "ignite" the gas or start it burning. Then as the gas burns its temperature and pressure will rise very rapidly. If the gas were burned in the open the temperature would go quite high, but when burned in a confined space the pressures are increased as the gas burns. The increase in pressure adds to the heat (as in the case of the tire pump), as does also the burning of the fuel. Therefore, we obtain a temperature in a gas-engine cylinder between 2,000 and 2,500 degrees Fahrenheit. You can think of this as a white-hot flame.

Heat Loss.

5. Let us imagine we have a cylinder and piston so arranged that we may compress a charge of gas and then lock the piston so that it can not be moved, and let us also imagine that there is absolutely no leakage. Now, if we ignite this compressed gas, our temperature and pressure will instantly run up very high. But should we leave it for five minutes before testing the pressure in the cylinder, we should probably find but few ounces of pressure. Now, the reason for this is that the cool cylinder and piston have absorbed the heat of the explosion, and as the heat subsided the pressure subsided also. In other words, the hot gases have been contracted by cooling. In other

words, heat and pressure can be considered as practically the same thing in a gasoline engine.

6. Now we will stretch our imagination a little further. We will imagine that we have a cylinder which is not only capable of having gas compressed in it, and then the piston locked, but also can be maintained at a temperature in the neighborhood of 2,500 degrees. This temperature, by the way, is far above the melting point of iron. Now, if we can compress gas and fire in this cylinder at this temperature, we will find that the pressure will remain very high in the cylinder as long as we maintain the temperature of the cylinder. This is because the cylinder and piston will not cool the hot gases after the explosion. The result is there is no radiation or loss of heat from the explosion which is commonly called "heat loss."

7. With the best gasoline motors we make use of only about 20 per cent of the heat value of the fuel, or, in other words, we lose $\frac{4}{5}$ of the heat or power that is in the fuel.

8. To show where this heat or power goes, suppose our fuel were 100 per cent fuel value. About 5 per cent of this is consumed in friction, 35 per cent is lost by radiation, mostly to the water jacket, and 40 per cent goes out of the exhaust valve and is lost. This leaves only about 20 per cent to be delivered in the form of power.

9. These figures are only approximate, but should serve to give an idea of where all our power or heat goes.

10. Now, after explaining heat loss, it may seem odd that we find it necessary to cool the motor. However, I have already explained that the temperature of the explosion is sufficient to melt an ordinary iron cylinder, and long before the temperature reached that point the piston would expand and stick in the cylinder; also, lubrication would be destroyed by the burning of oil and the babbitted bearings would be melted out. Obviously, then, the motor must be maintained at a temperature sufficiently low to permit lubricating oil to work properly. However, there is a limit to the temperature at which a motor can run, which is still lower than the limit set by the burning of the lubricating oil. Remember that I have explained that if we compress gas it becomes heated, and also we must remember that up to a certain point the more we compress the gas before

firing the more power we obtain for a given amount of fuel. However, if we compress the gas to excessive pressure, the heat of compression will ignite the gas and will ignite it long before the proper time—in other words, before the piston nears the top of the stroke—and the result will be a tendency to drive the piston backwards. Suppose we have an engine designed with the proper amount of compression; if some portion of the cylinder becomes red hot or even approaches that temperature, the heat of this portion, together with the heat of compression, will be sufficient to ignite the gas—in other words, cause what we call "preignition."

Cooling.

11. There are two methods used at present for cooling. One is by air cooling direct and the other through the medium of water, which is later cooled by the air.

12. To begin with, let us remember that a square inch of metal will radiate or give off a certain amount of heat in a given time. The more square inches of surface we have on the outside of a motor cylinder the more heat can be radiated or given off in a given time. We are all familiar with the appearance of a motor-cycle cylinder. It is constructed with numerous fins or ridges around the cylinder, the purpose of which is to present as many square inches of surface to the air as is practical.

13. Remember that the more air that passes a square inch of metal, in a given time, the more heat the metal will be able to give off or radiate. Therefore, we find large air-cooled motors, arranged with a blower of some description which will cause a large amount of air to flow by the cooled flanges on the cylinders, and frequently there are jackets or housings around the cylinder which will force the air to flow between these cooled flanges. This applies to motors which have stationary cylinders. In the case of rotary motors, which we will take up later, the cylinders are passed through the air constantly and therefore no fan or blower is required.

14. The other method of cooling motor cylinders is to construct them with a double wall and fill the space between the two walls with water. Then as this water is rapidly heated

by the explosion inside the cylinders, we must have means of removing the hot water and replacing it with cool water. For a stationary motor, we might use a large tank of water to draw from, and pump the hot water from the cylinders back into this tank; but in airplanes and automobiles it is necessary to carry a small amount of water for the sake of light weight; therefore we must have a means of rapidly cooling this water.

15. You all know that the way to cool a dish of hot mush is to spread it out thin, in this way exposing many square inches to the air. If we could carry a tank so arranged that the water can be spread out over a hundred square feet and not more than a sixteenth of an inch deep, this would make an ideal radiator as far as cooling is concerned, but would be far too bulky and we would lose water by evaporation. Therefore, we use radiators of various types. These radiators are so constructed that they spread the water in very thin layers, usually about the thickness of heavy paper. The water is enclosed in thin sheet copper, which is an excellent conductor of heat. Water heats the copper and the cooper is cooled by the air. In a well-designed radiator we expose a great many square feet of surface to the cool air. In this way comparatively small radiators can cool a large amount of water in a short time. In an airplane the radiator is drvien constantly through the air at a high speed, thus insuring an ample supply of cool air.

16. There are two methods of taking the water from the radiator to the cylinder and from the cylinder back to the radiator, or, in other words, circulating the water. First, we have the system which employs a pump of some type, usually a centrifugal pump. This pump circulates the water through the water jackets at the speed which is found to be best by the designer of the motor. Also, we have what we call the Thermo-Syphon system, or, in other words, heat syphon.

17. You all know that the hottest air in a room rises to the ceiling and the cooler air settles in the lower part of the room. This is due to the difference in weight of the hot and cold air. The same thing is true with water in a tank. If you fill a tank with warm water, very soon you will find comparatively cool water in the bottom while the water on the surface will be warm.

18. In the cooling systems of motors this works out as follows: The water in the water jacket surrounding the cylinder is being heated and is rising. It flows upward to the top of the radiator, and as it flows upward its place is taken by cool water from the bottom of the radiator; also in the radiator the water is being cooled, and as it cools it becomes heavier and settles to the bottom. In this way we have the heating of the water in the cylinder and the cooling of the water in the radiator, causing the water to circulate continually. This system has the advantage of simplicity and also of keeping the cylinder head comparatively hot even when the motor is run slowly. However, it requires larger water jackets and water passages, which mean more weight, and this is probably the reason it is not used in airplane work. With the pump or force circulation systems we find the designers taking advantage of the Thermo-Syphon principle in this way. Water is always introduced at the bottom of the water jacket and removed at the highest point of the water jacket, delivering to the top of the radiator and drawing from the bottom. In this way the Thermo-Syphon principle helps the pump instead of hindering it.

LECTURE II.

COMPARISON OF AIR AND WATER COOLED TYPES.

1. The air-cooled motor can run at higher temperatures than the water-cooled motor, and as there is less difference in temperature between the cylinder walls and the heat of explosion there is less loss of heat by radiation or less "heat loss." The air-cooled system is simpler and sometimes lighter than the water cooled. It has no freezing troubles in winter, but as it runs hotter this means lower compression must be used, because on hot days, with the atmospheric temperature higher, the cylinder temperature may be several degrees hotter. In other words, the designer has no definite upper limit on his temperature and must make the combustion chamber of a size which will give a compression suited to the highest likely temperature. This means comparatively low compression. With water-cooled motors, as the water temperature reaches 212

degrees (boiling point of water) the water is rapidly lost. Therefore there is quite a definite upper limit to the temperature at which this type of motor can be run, and this means that a comparatively high compression can be used and better fuel economy obtained.

2. When a motor has excessive compression, it will run well for a short time, then will lose power from pre-ignition. Airplane motors are particularly likely to be troubled with pre-ignition, because of the fact that they are run continuously on full throttle, which also means full compression.

Types of Motors.

3. The type of motors with which we are all familiar is the vertical, where the cylinders are arranged in a row, standing vertically over the crank shaft. Motors with one, two, three, four, or six cylinders nearly always are made in this type. If we attempted to make eight cylinder motors in this type with the cylinders in line, it would make a very long motor which would take too much room in the airplane fuselage and also the crank case would have to be made quite heavy in order to be stiff enough. Eight and twelve cylinder engines can be built with the cylinders in line or vertical for marine purposes, but are not likely to be built in that way for airplanes.

4. Suppose we decide to build an eight-cylinder motor. Now, if we can arrange the cylinders in two rows of four, side by side, we cut in half the length and weight of the crank shaft, cam shaft, and crank case, thus making the motor lighter, more compact, and more rigid.

5. We have airplane motors built of still another type, where the cylinders are placed around a single crank pin in the same manner as the spokes of a wheel are placed around the hub. We call this the radial type. This type gives a very short and rigid shaft. The crank case also is a strong barrel type of case not divided in the center. Also it is possible with a crank shaft like this to use ball bearings satisfactorily.

6. This type of motor is built both in the air and water cooled types. In the air-cooled form it requires no fan or blower, because the cylinders are so placed that the air will reach all of them evenly without any blower or jacket. There

is a tendency for the lower cylinders to become flooded with oil, but this has been satisfactorily overcome by constantly pumping the oil out of the crank case and not allowing it to accumulate there. This type of motor is hard to enclose in a stream-line hood and therefore has not been used on high speed machines.

7. We have still another type of motor built with the cylinders arranged in the same manner as radial motors but operating differently. Up to the present, we have considered only stationary cylinder types in which the cylinders remain stationary and kick or drive the crank shaft around. Others are known as rotary or, correctly speaking, rotating motors. The cylinders and crank case are similar in arrangement tó the radial type.

8. In the rotary type of engine, the crank shaft is bolted to the airplane and the propeller is attached to the crank case, just the reverse of the practice with stationary cylinder motors. The crank shaft then stands still and the cylinders drive themselves around it. With this type of motor, we have to deal with centrifugal force. In other words, there is a strong tendency for the cylinders to be thrown away from the center of the engine. This makes a steel construction necessary, and in order to reduce this strain as much as possible, the cylinders are built of steel with very thin walls of very light construction.

9. The rotary engines combining the principles which tend to lighten the weight, as in radial motors, with an extremely light all-steel construction, are the lightest motors now in use. But, unfortunately, they consume so much fuel and oil that if we weigh them with fuel for a long flight, they are heavier than the stationary cylinder types; but for short flights, they remain the lightest. The reasons for their excessive fuel consumption are, first, that as they are air cooled they have comparatively low compression; and also that they require between ten and twelve per cent of the power they develop to rotate the engine, or drive the cylinders through the air.

Types of Cylinders.

10. There are two main types of cylinders used. They differ in location and operation of their valves, and also in the form of their combustion chambers. The "L" head type has the

valves side by side in a pocket at one side of the combustion chamber. The valves are operated by simple cam followers or plugs riding upon the cam shaft which is in the crank case. The cams raise the followers which raise the valves, making a simple valve gear. This design makes room for long valve stem guides and springs, and there is a straight thrust on the valve stem and no side thrust which tends to wear the guides.

11. The valve in the head type of cylinder has the valves placed either vertically or at a slight angle apart, with the heads of the valve seating in the head of the cylinder. This gives a combustion chamber that has no pockets, but the valve must be operated by push rods and rocker arms or else the cam shaft must be placed along the top of the cylinder with small rocker arms operating the valve direct from the cam. In this case the cam shaft is held in an oil-tight housing.

12. Now, I will ask you to recall the explanation of heat loss in the first lecture. You will remember that a large amount of heat was lost by radiation, or by the interior surfaces of the combustion chamber absorbing heat. The more square inches of surface exposed to the heat in the combusion chamber, the more heat will be absorbed and the greater will be the heat loss. Evidently then, the combustion chamber which exposes the least surface to the heat will cause the least heat loss. This also works another way; the cylinder exposing the least surface to the heat of combustion in the combustion chamber will require the least cooling. This may mean reduced weight in the cooling system. In the case of high speed motors, it is extremely important to have very direct gas passages. In other words, the gas should be able to go straight into the cylinder and straight out without having to flow around any corners or through pockets in the side of the cylinders. The "valve-in-the-head" type of cylinder gives a more direct gas passage, which means such a cylinder can receive a more complete charge of gas at high speed and the exhaust gases can be more completely expelled or scavenged.

Spark Timing or Spark Advance.

13. Up to the present, we have considered ignition of gas as occurring when the piston is at the top of its stroke. It is

important to ignite the gas or start it burning at such a time that it will be completely burned and ready to do work by the time the piston starts down. If our motor is run at an extremely slow speed we can ignite the gas when the piston is at the top of its stroke, and as the combustion or burning of the fuel is quite rapid, the fuel would be completely burned by the time the piston starts down. But, if the motor is run at high speed, the crank shaft will turn many degrees during the time that the gas is burning and if we ignite the fuel when the piston is already at the top of the stroke, the gas will not be completely burned and the maximum pressure will not be obtained until the piston is already very far down on the working stroke. Therefore we will not get all the power from this explosion.

14. In high-speed motors the spark must occur far enough before the piston reaches the top of its stroke so that the fuel will be completely burned and the maximum pressure and heat obtained by the time that the piston starts down. Therefore, the faster our motor runs the earlier the spark must occur; also, it makes considerable difference to the spark timing if we use different shaped combustion chambers.

15. For example, if we use the "L" type of cylinder with one spark plug at one side, the flame will have a long way to travel to pass through the entire charge of gas. This means that it requires a long time for the gas to be completely burned, and such a type of cylinder will require an earlier spark, or more spark advance, as we say.

16. It is desirable, then, to use the most compact combustion chamber we can, and we frequently use the two spark plugs in each combustion chamber, as far apart as possible. In this case, lighting the gas at two points, it requires less time for complete combustion.

17. The "valve-in-the-head" type of cylinder has the most compact combustion chamber of any type at present. I wish to state here that when we crank our motor by hand we are turning it over at a very low speed, and therefore we set the spark to occur very late, frequently after the piston has already started down, because, if we did not, it would be possible for the explosion to drive the piston backwards because of its slow movement. This is known as a "back-kick," and is always dangerous to the man cranking the motor.

Multi-Cylinder Engines.

18. You will remember that with the single cylinder engine we found that we had one working stroke, followed by three idle strokes, and a fly-wheel was necessary in order to carry the engine through the three idle strokes. With this engine our power comes in jerks. There is not a steady flow of power from the engine, and if there is a heavy piston and connecting rod moving up and down, with nothing to balance it, the motor causes considerable vibration. While this type of motor can be balanced with a counterweight on the crank shaft, it never works very smoothly.

19. Now, if we build a four-cylinder engine, we will arrange the cylinders to fire once for every stroke of the piston. In this case there is a much steadier flow of power or, in other words, a much more even torque, and it is usually arranged so that there are two pistons moving upwards and two moving downwards at the same time, thus partially balancing the engine.

20. With the six-cylinder engine, we have still more even torque and better balance, and with the eight or twelve cylinder engine we have a very steady flow of power and comparatively good balance and smooth running.

21. Now the advantages of a multi-cylinder motor over a motor with fewer cylinders are as follows: First, each piston and connecting rod is smaller and therefore lighter. These parts are called reciprocating parts because of their back-and-forth motion, and it requires a great deal of power to start and stop these parts in a high-speed motor. Therefore it is essential that they be as light as possible. When we have few cylinders of large diameter we have much more difficulty due to unequal expansion. With smaller cylinders there is less of this difficulty. With a multi-cylinder engine we have little loss of speed and power when one cylinder fails for any reason.

22. In all multi-cylinder engines all the cylinders fire during one complete cycle (2 revolutions), and nearly all of them are arranged so that the cylinders fire at even intervals.

23. For example, a four-cylinder engine fires four times in two revolutions, or twice in one revolution, which means the cylinders fire one-half a revolution or 180 degrees apart. A

six-cylinder engine fires every 120 degrees; an eight-cylinder, every 90 degrees, and a 12-cylinder, every 60 degrees.

24. The length of the working stroke is from the top center to the time the exhaust valve opens. Let us say, for example, 135 degrees. If the four-cylinder engine fires every 180 degrees, there is an interval of 180 degrees minus 135 degrees, or 45 degrees, when there is no pressure to turn the crank shaft ahead, and the fly wheel must do it.

25. In a six-cylinder engine the cylinders fire every 120 degrees, which is less than the length of the working stroke, so the working strokes overlap 15 degrees. This means smooth running. In an eight or twelve cylinder engine the working strokes overlap still more.

26. In all high-speed airplane motors it is quite a problem to cool the piston head. In fact, it is usually this part of the engine which limits the amount of compression we can use. The piston head is cooled mainly by the heat flowing through its metal to the comparatively cool cylinder wall. If the piston is large the heat has further to travel from the center to the sides, and it is quite difficult to keep this piston head below the temperature at which it would ignite a charge of gas under compression. The only way we can use very large-sized pistons is to reduce the amount of compression. By so doing the charge is less easily ignited by hot parts and less heat will be generated with the low compression, but it means less fuel economy.

27. The advent of the aluminum alloy piston has been a help in the solving of this problem, because aluminum conducts heat about three times as fast as iron or steel, which were formerly used for pistons.

28. In practice the multi-cylinder, small-bore engines are not *necessarily* more efficient or economical than the larger bore engines, because they expose more surface to absorb heat in proportion to the cubic feet of gas handled. Also, there is more friction in the multi-cylinder motor.

Lubrication.

29. Lubrication consists in introducing some substance—for example, oil—between two rubbing surfaces, to reduce the friction and wear that otherwise would occur. No matter how

smooth a metal surface may appear to sight and to touch, it is in reality covered with tiny ridges and hollows, that are easily seen under a microscope. So when two clean, smooth metal surfaces are placed together and caused to slide over each other, these little ridges engage each other, or interlock, and naturally some of the projections are torn loose from each piece. This tearing away of metal is known as wear, and the resistance to the tearing is known as friction. When oil or grease is put between the two surfaces it fills the little hollows and forms a thin film, or layer, that prevents the metal surfaces from *actually* touching each other except at the highest points of the largest of these microscopic ridges. The result is a smaller number of these ridges torn loose; therefore, less wear, less friction, and less heat generated.

30. This oil film must be maintained in bearings. If it is not, excessive wear always results. In large, heavy duty machinery it was found that the oil film could be maintained by making the bearings large in area, so that the pressure per square inch would not exceed a certain point, beyond which the oil film would be destroyed.

31. In airplane motors it is impossible to use bearings of this size on account of weight. Therefore it has been found possible to maintain the oil film by the use of a large volume of oil pumped through the bearings under very high pressure; but space must be left in the bearings for this oil film, and also it is necessary to leave space and clearance in the bearings so that oil can be pumped through.

32. You can easily imagine that a heavy film of oil could not be forced through a bearing which had only a thousandth of an inch clearance. Motors using these high-pressure systems frequently have the bearings from two thousandths to four thousandths of an inch loose, thus allowing the crank shaft to run on an oil film instead of on babbit metal. This means less friction and less wear on the bearings, but it requires a high oil pressure.

33. I can now point out that in deciding how tight to adjust the bearings of a motor we must first consider the nature of the oil system. If we have a high oil pressure system, we can fit the bearings quite loosely. In fact, we must fit them loosely

or excessive wear and excessive oil pressure will result. But should we have a motor using a splash system, gravity feed system, or very low pressure we could not leave the bearings loose, because if we did the bearings would hammer out quickly. With such lubrication systems we must adjust the bearings closer.

34. Another thing to be considered before adjusting the bearings is whether we are simply adjusting bearings which have been run and are worn to a perfect bearing surface or whether the bearings in question have been newly scraped or fitted and have not worn to a perfect bearing surface. In the case of the worn bearings they will not loosen up rapidly, and therefore can not be adjusted as tightly as the bearings which have been scraped, have not a perfect bearing surface, and will therefore loosen up rapidly at first.

35. Nearly all of our modern airplane motors use this high oil pressure system, generally having a gear pump in the crank case delivering oil to some tube running the full length of the crank case which acts as an oil distributor. Sometimes the cam shaft is used for this purpose. In any case, we find oil ducts leading from this tube to the main bearings of the crank shaft, and here we must see to it that the oil holes in these bearings register with the oil holes in the crank shaft, as oil is usually expected to flow into the crank shaft through the arms of the crank, out of the crank pins and connecting rod bearings. The oil is thrown from the connecting rod bearings up on the piston and cylinder walls and also the wrist pins or piston pins. The older motors always had dip pans or splash pans, arranged under the crank shaft in such a way that the connecting rods could dip into the oil and splash it to all parts of the motor, but as the airplane motor operates in all positions, such systems proved unsatisfactory, because when in some positions the oil from these splash pans would flood the cylinders and combustion chambers, causing various troubles, such as foul spark plugs and carbon deposits.

36. Our modern engines have no splash pans and have a pump which will keep all excess oil drained from the crank chamber and usually have a small oil sump under the crank

case, but not connected to it in such a way as to allow the oil to flow up into it. In other words, the oil is pumped into the lubrication system and the crank case is constantly pumped dry so that there will be no accumulation of oil in the crank case, which might flood the cylinders in the case of the motor operating in extreme positions.

37. Oils used in motors are usually the mineral oils. Castor oil has been used in some types of motors where the oil is not used over and over again. Castor oil, if used over and over, will congeal or thicken. It is useful in rotary motors because it is not mixed with gasoline in crank case and because of its high viscosity or ability to cling to the cylinder walls under high temperature and under the influence of centrifugal force encountered in that type of motor. It is finally thrown out of the exhaust valves and lost, which accounts for the high oil consumption of this type. The desirable qualities for motor oil are first of all that it should burn only at very high temperatures. In other words, it is said to have a high fire test. This is necessary to stand the high temperatures in the motor cylinders. Next, it should maintain its viscosity or body at high temperatures and after using it should show very small percentage of decomposition so that it will be suitable for use over and over again in the motor. Also it should have a low carbon content so that it will not leave excessive deposits of carbon in the combustion chamber. As a rule, a heavier oil deposits more carbon than the lighter oils. Lighter oils must be used in very cold climates because heavier oils become too thick, and in tropical climates the heavier oils must be used as the lighter oils fail to retain sufficient body under high temperatures.

38. The oil in a motor must be changed from time to time, that is, all the old oil from the lubricating system must be removed and new oil must replace it. Some of the reasons for this are, first, that the oil in being thrown from the crank pin or connecting rod bearings comes in contact with the under side of the piston head and becomes partly burned. In this way it is turned black and has a large amount of carbon in it. Also it becomes full of metal particles from the wear of the bearings; and still another reason more recently discovered is

that when we are using low-grade fuels in our motors a certain proportion of this fuel fails to burn and mixes with the lubricating oil, thus thinning the oil and impairing its lubricating qualities. In other words, it is poor economy to try to use oil too long.

LECTURE III.

VALVE TIMING.

1. The valves of a motor must open and close at exactly the right time in order to let the new gas in and the burned gas out of the cylinder at the right time; also it is important to let a good, *full*, charge of gas in and to scavenge or clean out the burned gas as completely as possible.

2. Beginning with the working stroke: At the beginning of the stroke the pressure is often between three hundred and four hundred pounds to the square inch (approximately four times the pressure of compression). As the piston is forced down in the cylinder the gas expands and pressure becomes less and less.

3. Finally a point is reached where the pressure is down to fifty or sixty pounds per square inch and the crank is at an angle where the pressure has but little effect on it, and there is not much to gain by keeping it in the cylinder any longer. There is also a large amount of cylinder wall exposed to absorb heat; and if the gas is kept in the cylinder, overheating will result. Therefore it is usual to open the exhaust valve some distance before the piston reaches the bottom of its stroke or the crank reaches "bottom center."

4. There is another reason for opening the exhaust valve before bottom center. We wish all the pressure in the cylinder to rush out before the piston starts up, because if it did not the piston would have to be forced up against it and a loss of power would result.

5. The exhaust valve is kept open all the way up the exhaust stroke and slightly after the top center so the piston can push out as much of the burned gas as possible. If it is held

open too long, the piston will draw back some of the burned gas as it is started down, and if closed too soon the cylinder will not be completely scavenged. So we see that the closing of the exhaust valve must be quite accurately timed. The inlet valve usually opens at the same time the exhaust valve closes, or a few degrees later, because we wish to use the full length of the suction stroke.

6. The piston goes down very rapidly in a high-speed motor and there will not be time for a sufficient amount of mixture to pass through the inlet valve to give the cylinder a full charge. In other words, there will still be suction, or a vacuum, in the cylinder at the end of this stroke. Therefore the inlet valve is held open for a considerable period after the piston reaches the end of its stroke and starts up on the compression stroke. Although the piston is traveling upwards, gas will continue to flow into the cylinder on account of the suction remaining.

7. There is another reason why the gas will continue to flow into the cylinder. There is a large column of gas in the inlet manifold which has considerable weight, and during the downward stroke of the piston this column of gas attains considerable momentum and this momentum will continue to force gas into the cylinder, even after there is no more suction in the cylinder. So we see why a motor will get a more complete charge of gas if the inlet is held open some distance after bottom center. (Note.—The faster the motor runs, the longer the valve is held open.)

8. The exhaust valve opens from forty to fifty-five degrees before bottom center on different motors. (The crank can be set to this angle by using a protractor, and the piston position measured while the crank is in this position, so we will know the correct piston position when we come to time the valves. It is usually more convenient to time airplane engines by piston position than by degrees or crank angle because they use no fly wheel.)

9. The exhaust valve closes on top center or within fifteen degrees after top center, varying on different motors. The inlet valve opens at the same time the exhaust valve closes or possibly five or ten degrees later. (In a few engines, the inlet valve opens a few degrees before the exhaust valve closes.)

The inlet valve closes from thirty to fifty degrees past bottom center.

10. The above timing refers to all stationary cylinder types of four-cycle engines now used in airplanes, but is not correct for the Gnome rotary engine.

Method of Timing Valves.

11. The process of timing the cam shaft in a motor consists in, first, placing the crank and piston of one cylinder in the correct position for the exhaust valve to close. (NOTE.—We always time the crank shaft by the closing of the exhaust valve because this must be more accurately located than any other operation that the cam shaft performs.)

12. Second, we turn the cam shaft separately in the direction in which it runs until it just allows the exhaust valve to close. Third, we mesh the gears or connect the two shafts together. If we remember this simple explanation, we are not likely to go wrong on the valve timing.

13. The exact method of meshing gears or of placing the crank shaft and the cam shaft will vary somewhat in different motors, but the principle remains the same.

14. *It is very important* to adjust the valve clearances *before* timing the cam shaft, because a small variation in clearance makes a large variation in valve timing. If we should time the cam shaft without previously adjusting the clearance, then adjust the clearance afterwards, this would throw our valve timing out or make it incorrect.

15. Now I will explain in detail the process of timing the cam shaft on a Curtiss OX2 motor, eight-cylinder, " V " type. First, we will adjust the valve clearance. At the present time these clearances are supposed to be ten-thousandths of an inch on each valve. Then we will remove the cam-shaft gear-retaining screw and pull the gear partly off the cam shaft, far enough so that it no longer engages with the crank-shaft gear but still engages the key on the cam shaft. This makes it possible to turn either shaft independently. Now we will remove the spark plug from No. 1 cylinder and insert a rod or scale and turn the crank shaft in the direction of rotation until

we place the piston exactly on top center. We now have a point to measure from. The instruction book for this motor will tell us that the exhaust valve should close one thirty-second of an inch *past* the top center. Therefore we will make a mark on our rod or scale just even with the top of the spark-plug hole and will measure one thirty-second of an inch up from this point and make another mark. As the book told us the valve should close one thirty-second of an inch *after* top center, we will turn the crank *ahead* until the piston has gone down one thirty-second of an inch. We can now see that the crank shaft and piston in No. 1 cylinder are in the correct position for the exhaust valve to close.

16. Second, we will turn the cam shaft *in the direction in which the cam shaft revolves* until the exhaust valve is open, and keep on turning until the exhaust valve is *just seated.* By this I mean not until we have full clearance at the exhaust valve, but just until the tappet screw in the rocker arm is just leaving the end of the valve stem. Another method of determining this is previously to insert a cigarette paper between the tappet screw and the valve stem and when the cam shaft is moved far enough to allow this paper to be slipped out without tearing, that will indicate that the valve is just seated. (NOTE.—A cigarette paper runs one one-thousandth to two one-thousandths of an inch in thickness.)

17. Now we can see that our cam shaft is in the position where it is allowing the exhaust valve to close, or that the exhaust valve is just closed. Therefore we are ready for the third step, or meshing the gears. All that is necessary to do this is to push the gear on to the shaft, but it is possible that after we have placed both our shafts the gear teeth may not be in position to mesh. In this case we will have to decide whether we prefer to shift the cam shaft a fraction of a tooth forward or backward. Probably shifting it backward will be safer, because it is important that we do not allow the exhaust valve to close before top center. Then, having meshed the gears, the valve timing will be correct for the entire engine, because the cams are so spaced on the cam shaft that having timed one cam correctly the rest will follow in proper order. In airplane work, when we are timing the cam shaft or the magneto, we do

not consider the process complete until we have "checked" the timing. The simplest way to check the exhaust valve timing is to crank the motor in direction of rotation until the exhaust valve is just closing. Find this point accurately, as I have just explained, then place the rod through the spark-plug hole and make a mark. Now, this mark represents the place where the valve actually does close. Then, if this is supposed to be after top center, let us *back* the engine until we reach top center. Then make another mark. By measuring the distance between these marks we know exactly where the exhaust valve is closing.

18. The same method of checking applies to spark timing with the exception that we watch the breaker points instead of the exhaust valve clearances.

19. Occasionally a bad cam shaft is received from the factory. If we had a mysterious trouble in the engine that no one could find the cause of, it would be well to check the valve timing in every cylinder of the motor, and check not only the closing of the exhaust valves but every operation which the cam shaft performs.

LECTURE IV.

FUEL AND CARBURETION.

1. Nearly all the fuels now in use for internal-combustion motors are distilled from petroleum. Alcohol is not used to any extent as yet. I will explain briefly the methods of distilling lighter fuels from petroleum. The petroleum is heated usually by means of steam pipes, in order to avoid danger of fire, and when heated to a comparatively low temperature at first the lighter elements come off in the form of vapor. The first vapor to come off when condensed will be the liquid known as ether. If the petroleum is heated to a higher temperature, high-test gasoline will come off in the form of vapor. Then, by heating the petroleum to a greater temperature, low-test gasoline will come off. Now, as to the next products, that will depend upon the kind of crude oil used.

2. There are two general classes of crude oil or petroleum. Most of the eastern oil is what is known as paraffine base oil. Most of the western is known as asphalt base oil. In the case of the paraffine base, after the low-test gas, next comes kerosene, usually in large quantities. In the case of the asphalt base, the next product below gasoline is distillate or naphtha. After kerosene or distillate we get light lubricating oils, and by heating the crude oil to a still higher temperature we obtain cylinder oils or heavier lubricating oils, and so on through the oils, until we come to the tar products and vaseline. The chemists divide these various products into many different varieties.

3. I will explain what is meant by high-test and low-test gasoline. High-test gasoline is very light and volatile, and evaporates very rapidly if left open, while low test is heavier, less volatile, and will not evaporate so easily. The gasolines are tested by the Baumé gravity scale. Formerly the gasoline of high test would show 72 degrees on test, but at present ordinary automobile gasoline tests about 60 degrees.

4. As the demands for gasoline have increased in the last few years, the oil refineries have been forced to mix many of the heavier fuels with gasoline. For instance, distillate; and then, in order to make the gas test properly, they have added some of the higher test fuels. In other words, the present-day gasoline may be a mixture of everything above gasoline and a good deal that is below and mixed in such proportions that the result will serve as gasoline.

5. There is also another method of obtaining gasoline. This is by compressing natural gas to a very high pressure and practically wringing liquid gasoline from it. For instance, after oil wells have been pumped dry they often yield gas which is useful for this purpose, and in certain districts there are gas wells which are useful in the same way. This gasoline is known as "casing-head" gasoline.

6. Carburetion is the process of mixing fuel with the air. Gasoline will burn rapidly and cleanly only when mixed with a large proportion of air. Now, the problem is to mix the gasoline and air rapidly in a comparatively small and light mixing device. That is the first part of the problem, we will say. Originally, with the first gasoline engines, the gasoline used

was of high test and would combine or mix with the air very easily. In fact, it was only necessary to draw air over a large surface wetted with gasoline and the air would become saturated with the gasoline vapor and was readily burned in the motor. But the present-day gasoline will not mix in this manner.

7. There are two methods for mixing gasoline with air. The first is to break the gas into very fine spray, and the other is to vaporize it by heat. Usually a combination of these two methods is used.

8. I will now try to make plain the method of breaking the gasoline into a fine spray. Let us start with the stationary gasoline engine, running at a constant speed. We will have a straight pipe, for instance, 1½ inches in diameter, running to the gas engine cylinder, so that the piston will draw air through this pipe during the suction stroke. Then we will have a nozzle or jet in this pipe, placed in such a way that all air must pass it. We will feed gasoline to this nozzle from a float chamber located beside and just outside the pipe. This float chamber will be so arranged that when the gasoline reaches a certain height, for instance, even with the top of the nozzle, the float will close the valve and stop the gasoline from rising any higher. This is a simple device for the purpose of maintaining the gasoline at a constant level. With an arrangement like this, the gas will feed through the nozzle equally well with the tank full or nearly empty. Now, as the air goes through this pipe to the cylinder, it will pass the spray nozzle with considerable speed and will pick up or suck up a certain amount of gasoline from the nozzle. In this way the gas will come out of the nozzle in a fine spray and will be fairly well mixed with the air by the time it reaches the cylinder, and during the compression stroke the heat of the cylinder and the heat of compression will help unite the particles of gasoline with the air.

9. By using a simple carburetor, such as I have described, if we should try to slow the motor down by closing the throttle valve between the spray nozzle and the cylinder, the air would flow past the nozzle so slowly that it would no longer pick up gasoline, or in any event, it would not flow rapidly enough to

break up the gas, even if it should draw some out of the nozzle. So we see that our carburetor is not suitable for variable speed.

10. Our next step will be to put a choke tube in this carburetor, or, in other words, a restricted air passage at the point where the spray nozzle is located. By this means we can make the air passage so small that even when the engine is running quite slowly there will be sufficient air velocity at the spray nozzle *to pick* up and *break up* the fuel.

11. Having decided to restrict this air passage at this point, the next problem is of what form shall we make this choke tube. We must choose a form of choke tube which, while it is small enough to get the desired air velocity at low speed, will still permit a large amount of air to flow through. We find that the Venturi form of air passage is best adapted to this purpose. It is practically an air nozzle so formed that the side in which the air enters is at rather an abrupt angle, but the side through which the air leaves is at a gradual angle, or, in other words, allows the air to expand gradually on the other side. This has the following advantages: First, that this form of opening allows more air to pass through for a given size than other forms, and also that as the air is expanding as it passes through, there is a tendency for the jet of fuel from the nozzle to burst apart into a fine spray.

12. Now, having put this choke tube, or throat, as it is sometimes called, in our carburetor, we will see how it works. Evidently our motor will run nicely at slow speed, but when we open the throttle to allow the motor to run very fast we will have trouble, because, as the suction of the engine increases, we find that the flow of gas from the spray nozzle will increase faster than the flow of air through the choke tube. This is in accordance with a certain law of physics. This means that our mixture of gasoline and air will become richer as the engine speeds up; *richer* means that there will be too large a proportion of gasoline for the amount of air. Therefore we must find some means of diluting this mixture at high speeds. We will make a large air opening between the spray nozzle and the cylinder, and we will put a valve in this opening, which will be held closed by a light spring. This spring will hold the valve closed while we are running slowly, but as the motor

runs faster and the mixture tends to become richer, the suction will open the valve and allow enough air to come in to dilute the mixture and make it right, provided the spring is properly adjusted. This we will call an auxiliary air passage and auxiliary air valve. The air passage in which the nozzle is located should be called the main air passage.

13. This diluting of the mixture at high speeds is one of the problems of carburetor work. One form of carburetor accomplishes this by having two jets, one working on the principle which I have described, so that it delivers a richer and richer mixture as the speed is increased, and the other arranged on a different principle, so that it delivers a rarer and rarer mixture. In this way the two jets compensate each other. We will take up this particular carburetor later.

14. We find many forms of carburetors, but they are nearly all made on these principles that I have explained.

15. The action of the spring on the auxiliary air valve is considered faulty, because when we suddenly open the throttle there is a tendency for the valve to jump suddenly and move too far off its seat. The result is that it temporarily admits too much air, "starving" the motor. To correct this some manufacturers use what is known as a dash pot, to steady the action of the auxiliary air valve. This is simply a piston working in gasoline, or sometimes in air, in much the same manner as the piston in a shock absorber. As the air or gasoline is forced to pass through a comparatively small hole in the piston, the piston can not move rapidly. Some designers of carburetors go still further, and in addition to using the dash pot to prevent the air valve from opening too far or too suddenly they use what is called a metering pin, which is an arrangement whereby the opening of the auxiliary air valve will temporarily feed an extra supply of gasoline, to avoid the tendency of starving the motor when the throttle is suddenly opened.

16. Some carburetors have fixed jets of certain wire-gauge sizes, which are screwed into the carburetor and can not be adjusted. Others have nozzles with a pin-point valve screwed in or out of them, to change the size of the opening and the amount of gasoline flowing through them. These are called needle valves. Some carburetors have the needle valve con-

nected to the throttle by mechanical means in such way that the needle valve will be opened slightly as the throttle is opened, or, in other words, as the speed of the motor is increased.

Carburetor Adjustment.

17. Let it be clearly understood that when a mixture contains too large a proportion of gasoline it is called rich and the motor is said to be flooded, and when it contains too small a proportion of gasoline the mixture is rare and the motor is said to be starved.

18. When a motor is cold it usually requires a rich mixture to make it start easily. This is because the gasoline does not combine readily with the air. In order to accomplish this temporary richness of mixture for starting, most carburetors have a device usually called a priming or flushing pin, which will when operated depress the float or hold the float down in the float chamber of the carburetor, allowing the gasoline to rise so high that it will overflow through the spray nozzle of the carburetor, thus wetting the inside of the carburetor with gasoline and making it easy for the air passing through to pick up a heavy charge of fuel.

19. Another method is to have some form of valve between the spray nozzle and the place where the air enters the carburetor. By closing this valve we get greatly increased suction in the spray nozzle, thus picking up an excess of gasoline. Such a device is usually called a choker. It is usually operated from the pilot's seat while the motor is being cranked.

20. Most carburetors have two gasoline adjustments and an air adjustment; one gasoline adjustment for low speed and one for high speed. In addition to this we have a little set screw which allows the throttle valve to close more or less completely, according to its adjustment. This is to permit the motor to idle at the desired speed.

21. Before adjusting any carburetor the motor must be thoroughly warmed up and ignition system must be perfect. The valve operation and compression must be perfect and fuel must flow in a generous stream to the carburetor. Also the carburetor float chamber and spray nozzle must be clear. If there

are any loose joints in the pipe between the carburetor and the cylinders too much air will leak in and dilute the mixture. Therefore these joints must be tight.

22. I will try to explain in a general way how carburetors are adjusted. First, all adjustments should be in a medium position. In other words, halfway between the most and the least, of either air or gas, according to their functions. The low-speed gasoline adjustment should be opened two or three turns. The engine should be started and thoroughly warmed up. Then we will adjust the low-speed gasoline adjustment, and after we have adjusted it so that we are getting the best results we can adjust the high-speed gasoline adjustment while the motor is running at high speed. Then, having our mixture right, we can adjust the screw which limits the closing of the throttle until the motor runs at the desired speed for slow speed. If we try to make the motor run too slow, it will stop, and if we allow it to run too fast it will make landing of the airplane difficult, and there will be danger of the machine running into and injuring the man who cranks the propeller to start the motor.

Now we have made our gasoline adjustment suit the adjustment of the auxiliary air valve. If the auxiliary air valve is unnecessarily tight, our motor will throttle down nicely and respond nicely when opened quickly, but will fail to show the proper speed. Then, in that case, by loosening the auxiliary air-valve spring, or allowing the auxiliary air valve to open further, we will get a larger volume of air through the carburetor, giving the motor more complete charges of gas and gain higher speed. Accordingly, the gasoline adjustments will have to be reversed to suit this change in the air adjustment. In most of these carburetors we can make our gasoline adjustments suit almost any air adjustment, and in airplane work the amount of speed or revolutions per minute we can make is the most important part of our adjustment; therefore we generally aim to have the air valve open as far as possible. The limit to this is that if the air valve opens too far our spring is too weak, and the motor will take air through this valve instead of through the main air passage when we throttle the motor down, and also it will fail to respond when we open the throttle quickly. So let us see that we have the auxiliary air valve adjusted so that it will just stay seated or closed when the motor is running very slowly or idle, but not tighter than is necessary.

23. Most carburetors are provided with a means of drawing hot air from the outside of the exhaust pipe, for the heat helps to evaporate the particles of gasoline, or, in other words, helps the mixing of the gas with the air.

24. If cold air only is used, or if the motor itself is cold, the gasoline goes into the cylinders in "chunks," and therefore it is never completely mixed with the air and is never completely burned. The result is that a larger amount of gasoline must be fed to the motor. When heat is used, or when the motor is hot, the heat causes the gasoline to combine more thoroughly with the air and less fuel can be used. The result is that if we should adjust the carburetor properly when the motor is cold, the mixture would become too rich when the motor was thoroughly warmed up, which would make poor economy and cause trouble. If we adjust the carburetor properly while the motor is hot, then the motor may be difficult to start when it is cold and may run badly until it is well warmed up, but this can be taken care of by using the choker, which I have described before. The main thing is to have a correct, economical, and clean mixture after the motor is heated up.

25. If the mixture is too rich, it burns very slowly. The result is that the charge will be completely burned and the maximum temperature reached only after the piston has descended in the cylinder for a considerable distance. Thus, the greatest heat occurs at a time when there is a large amount of surface exposed to absorb it. The result is over-heating of the motor; also the heat will be very great at the time the exhaust valve opens, which would burn the exhaust valve and overheat the exhaust pipe. We lose power also, because the maximum pressure occurs late, after the piston has already completed part of the working stroke.

If the mixture is too rare, first of all, we lose power and have excessive vibration. Next, if it is still rarer, the motor will "spit" through the carburetor. This is known as a back-fire. It is supposed to be caused in this manner: This rare mixture also burns very slowly, so slowly in fact that there will be a flame remaining in the cylinder even after the exhaust stroke, and when the inlet valve opens to admit a new charge, the flame remaining in the cylinder will ignite the gas and the flame will travel down the inlet pipe to the carburetor. This is dangerous because it is likely to set fire to the airplane, especially if the gasoline pipes are leaking slightly, near the carburetor, which they often are.

The Zenith Carburetor.

26. This carburetor is used all over the world on airplane engines. It is of the so-called non-adjustable type. The only method of adjusting the carburetor is to remove the jets or the choke tube and replace them with other sizes. These carburetors are fitted with the proper size jets and chokes at the factory where the motors are tested and never require further adjustment. The Zenith is of the type of carburetor having no auxiliary air valve but using the compensating jet principle. In other words, it is has a main jet which delivers a richer and richer mixture as the suction is increased and a compensating jet which is arranged to deliver a rarer and rarer mixture as the suction is increased. To make the operation of these two jets plain, we will suppose that I am sucking lemonade out of a bottle, which corresponds to the "float chamber," with a straw corresponding to the main jet. The harder I suck on the straw, the more lemonade I can get (richer and richer mixture). Now, for the compensating jet. Suppose you pour lemonade from a bottle drop by drop into an open glass, this glass corresponding to the "well" in the carburetor. I would suck from the glass or "well" through a straw (corresponding to the priming tube or cap jet). No matter how hard I suck I get only the amount that you drop into the glass and some air. As I increase the suction in the straw and cannot get any more gas I get more and more air, or the mixture I get will be thinner, rarer, and rarer.

27. Now, I will try to explain the operation of the carburetor. (The names of the parts on the carburetor should be taught on the model at this point.) As we come to start the motor, we find that the gasoline has gradually flowed through the compensating jet and has filled the "well" to a point even with the top of

the main jet. If the motor is cold, we must close the throttle to take the charge, and as the pistons can draw air only through the priming tube they will suck up liquid in the well through the priming tube until the well is empty, thus giving us a rich mixture for starting the cold motor.

28. Now, if we open the switch and start the motor, it will run slowly with the throttle closed or nearly closed, and it will still be sucking only through the priming tube. But as the compensating jet supplies gasoline to the well and priming tube in very small quantities, the pistons will draw far more air than gasoline through the priming tubes. Therefore we can think of this priming tube as a miniature carburetor for running the motor idle. Now, if we open the throttle slightly the suction will be decreased in the priming tube and increased in the choke tube of the carburetor in the main air passage. Therefore the suction will naturally be transferred to the cap-jet, or outer jet, placed in the choke tube. We are now drawing this same amount of gasoline and some air from the "well" and compensating jet, but through a new route, viz. the cap-jet. Then as we open the throttle a little more the air velocity through the choke tube will increase and the main jet begin to deliver a small amount of gasoline. This main jet, you will remember, is the type which will deliver more and more gas as the suction is increased. We can call this main jet our *high-speed* jet.

29. As we use the priming tube for slow running it is not necessary to have the choke tube very small; therefore the suction will not increase around the main jet to the extent that it does in most carburetors. Also, the main jet is not quite large enough to supply the gas needed at high speed and relies partly on the jet which is fed from the compensating jet, and as this latter jet delivers a rarer and rarer mixture it will offset any tendency on the part of the main jet to deliver a richer and richer mixture; thus we will say the jets compensate each other.

30. This carburetor is provided with the usual screw adjustment to limit the closing of the throttle valve in order to make the motor idle at the proper speed, and also there is a small air adjustment which acts on the priming tube and affects the running of the motor only at the idling speed.

31. To take a charge when the motor is cold the throttle should be completely closed, and when the motor is not cold it should be very *slightly* opened, because if we took a charge with the throttle closed while the motor was hot there would be danger of getting entirely too much gasoline in the cylinders or flooding the motor. That is, there would be such a large proportion of gasoline to air that it would be impossible to ignite the mixture.

Action of Gasoline in the Inlet Pipes and Manifold.

32. After adjusting our carburetor to deliver the proper mixture of gasoline and air under all conditions, our problem is not yet completely solved. We have still to solve the problem of keeping the gas mixed. As the mixture leaves the carburetor it consists of air and a finely divided spray of gasoline. If we could see this it would resemble steam from a teakettle. Now, this mixture must be kept rapidly moving or it will condense; that is, the liquid will gather together in puddles in all the low places on the way to the cylinders.

33. One method of avoiding this condensation is by allowing hot air to flow to the carburetor or by heating the intake manifold from the outside so that the walls will be sufficiently hot to vaporize the liquid fuel which comes in contact with these walls. It is important to have the manifold of the same inside diameter as the outlet of the carburetor, because if it is larger the mixture will flow more slowly than it would in the carburetor and condensation will be the result. Allowing hot air to flow through the carburetor helps the gasoline spray to evaporate or combine with the air, but we must remember that if the mixture is heated too much it goes into the cylinder in a hot and expanded condition and, therefore, we don't get as much of it in the cylinder to compress. In other words, we do not get a good, full charge, and there is less oxygen to the cubic foot of the heated mixture.

34. Another problem connected with the handling of the mixture of gasoline and air is that with certain motors there is a tendency for the gas to reciprocate in the manifold, or, in other words, to jump back and forth. This is especially true in a six-cylinder vertical motor with the usual firing order.

The gas will be drawn toward one end of the engine by one cylinder and next it will be drawn in the opposite direction by a cylinder in the other end of the motor; thus a very hard condition has to be overcome and causes uneven gas distribution and condensation. The same condition exists in eight-cylinder "V" type motors if a single carburetor is used, because there is a variation in the suction from the two sides of the motor and a tendency for the gas to reciprocate between the two sides.

35. Most of the modern airplane engines of six-cylinder vertical and eight and twelve cylinder "V" type motors use a divided inlet manifold and a duplex or double-barrel carburetor. This effectually prevents any possibility of the gas reciprocating from one half of the motor to the other, because they get their gas from separate sources. The "duplex" carburetors have a single float chamber to supply the two sets of jets.

Things to be Remembered About Carburetors.

36. It is impossible to get a correct adjustment on a carburetor unless everything else about the motor is *right*. If a carburetor seems to need very exact adjustment, or, in other words, the motor seems to be sensitive, it is a pretty sure sign that something is not quite right. For instance, the ignition may be poor, or there may be air leaks in the inlet manifold or dirt in the carburetor, and under these circumstances no one can get a good adjustment. If a carburetor drips gas—that is, seems to leak—it may be that the float is set too high and shuts off the gasoline only after it is high enough to overflow through the spray nozzle. Or it may be that there is dirt under the float valve, which keeps it from seating properly. It may be a defective or leaky float valve. Frequently when the carburetor drips gasoline there is nothing the matter, and the gasoline dripping out is simply due to the fact that after we stop the motor the gas which was in the manifold or inlet pipe will condense and drip out through the carburetor. Therefore, when our carburetor leaks we must notice whether or not it occurs as soon as we turn on the gasoline before starting the motor, in

which case it would be trouble with the float, or whether it only leaks after running the engine, in which case it would be due to condensation and unavoidable.

37. Back-firing in a carburetor may be caused by too rare mixture or by an extremely rich one. Usually, however, it is a rare mixture. Either mixture can burn so slowly that there will be enough flame left in the cylinder, even after the scavenging stroke to ignite the new incoming charge of gas when the inlet valve opens. Sometimes the flame will reach the carburetor or make a noise. A leaky inlet valve can also cause a back fire if it leaks badly enough or sticks open. An engine can "pop" from two causes, either from back fire in the carburetor, which would indicate lack of gas or too much air, or possibly inlet valve trouble. The other cause for "popping" can be a very rich mixture or a very late spark. But there is a great difference in these two, because in the case of the former the pop will occur in the carburetor, and in the case of the latter it will be in the exhaust ports or exhaust pipes. So it is necessary to determine where the pop is occurring before attempting to find the cause.

Cold-Weather Starting.

38. In cold weather many people prime a motor with gasoline direct in the cylinder to help start it. There are objections to this method. For instance, if the motor fails to start on the first priming we are likely to find that we are losing compression, because the gasoline has washed the oil off the piston rings, and when the motor does finally start there will be danger of scoring or scratching the cylinder walls on account of the oil not being there to lubricate.

39. A better method of priming the motor is to turn it over as fast as you can with the switch safe or closed and the throttle half open, and while this is being done, completely stop the auxiliary air opening with one hand and nearly stop the main air passage with the other. This will cause high air velocity and suction at the spray nozzle. This method gets the gas into the cylinder in the form of a vapor or spray. The result is the motor is more apt to start and there is less danger of scoring the cylinders. Frequently it is possible to know when you have

a charge in the motor, because you can see the vapor coming out of the exhaust pipes by looking very closely. This applies to the case where the motor is cold. If the motor is hot there would be a certain amount of vapor present from other causes. Another good method of priming is to squirt gas through a cock in the top of the intake manifold or at the highest point of the manifold. In this way the gasoline will spread over the interior walls of the pipe and expose a large wetted surface for the air to pass over. In extreme cases it is a help to saturate a piece of rag with "ether" and hold over the air intakes of the carburetor while taking a charge. The motor can be started in this way when it refuses to start in any other way.

40. Nine times out of ten when the motor seems to have carburetor trouble the trouble is somewhere else. It seems as though the human race is prone to blame the carburetor for all troubles, possibly because it is the easiest thing to "monkey" with. Many times I have seen people adjusting a carburetor to correct a trouble caused by the magneto being wired up wrong. If the engine is missing or acting badly in any way and we believe the carburetor is to blame, we can find out or prove it in the following manner: If we have a carburetor of the auxiliary air-valve type, simply run the engine at the speed where it is giving trouble and raise the air valve slightly off its seat with one finger, thus temporarily making the mixture rarer; and if this does not correct the trouble try holding the hand partially over the air intake to make the mixture temporarily richer. If neither of these operations stops the missing or trouble, the fault absolutely is *not* in the carburetor, and if raising the air valve or thinning the mixture would seem to help the engine, that might only mean that there was dirt under the float valve, allowing gasoline to rise too high in the float chamber. and would not necessarily mean that the adjustments of the carburetor should be changed. It might also mean that we should have had more cold air and less heated air. If conditions seem to be improved by putting our hand over the air intake or making the mixture richer, that might mean that we had air leaks in the inlet manifold, no air vent in the gas tank, poor flow of gasoline to the carburetor through feed pipes, water in the gasoline, dirt in the spray nozzle, or weak exhaust-valve

springs. The chances are that there would be no real necessity for altering the carburetor adjustments to feed more gas.

41. Remember that we must not leave gasoline in the float chamber of a carburetor if the engine is not going to be run for a week or so, because some grades of gasoline when evaporating in a carburetor under these circumstances will leave a deposit which resembles wax or soft soap, and naturally when gasoline is turned on and the engine started, this deposit will clog some of the fine gasoline passages. In any case it is wise to inspect and clean the carburetor after the motor has been standing for some time without running.

42. Make it a rule never to connect the feed pipe to the carburetor without first allowing gasoline to run through the pipe to clean the pipe or flush it out and to prove the volume of the flow. If there is any doubt as to the amount of the flow through the pipes being sufficient you can prove it in this way: Suppose your motor burns ten gallons of gasoline per hour. You should not be satisfied with the flow of gas unless it will flow twice that fast, or two gallons in six minutes. When running gas through the pipe for the purpose of cleaning hold the end of the pipe as low as possible to insure all heavy dirt and water coming out of the end of the pipe, and when testing the amount of flow try to have the end of the pipe at the same height as where it connects with the carburetor in order to make it a fair test. To clean out the carburetor, we should begin at the gasoline tank and see that there is a good air vent in the tank, because gasoline can not flow out of the tank unless air is able to come in and take its place. (NOTE.—This refers to gravity feed.)

43. Then we should disassemble and clean out the float chamber, inspecting the float mechanism to see that nothing is working loose. We should clean out the strainers, wherever they may be located; clean the jets. A special socket wrench should be used to remove them for cleaning. Always remove one at a time, clean it and replace it firmly before removing another. See that a gasket is on it, but don't change the thickness of the gasket as this would affect the flow from the jet. Sand, water, or rust flakes are likely to be found in the jets. In the Zenith carburetor there are plugs under the jets which

make them accessible. These plugs also have a cup in them which catches dirt, and they should be cleaned out before being put back in place.

LECTURE V.

MAGNETOS.

1. In speaking of electric currents, we speak of the flow and the pressure in much the same way in which we would speak of the amount of water flowing through a pipe or of the pressure of water in the pipe. In electricity the amount of flow is measured in *amperage*, or number of *amperes;* and the pressure is called *voltage*, or we speak of the number of *volts* in a circuit. Then a high-pressure current would be called a high-voltage current. Low pressure would be called low voltage. We also use the expressions high tension and low tension. For ignition in a motor we require high-pressure or high-tension current, which will be able to force its way through the space between the spark-plug points. A high-tension magneto does three things: it generates a current, "steps it up," and distributes it, or "hands it out" to the proper cylinder at the proper time. The so-called low-tension magneto generates a low-tension current only and has a simple armature composed of a soft iron core with a single winding of wire.

2. The high-tension magneto has a double-wound armature. It is constructed with a soft iron core, then a primary winding composed of a few turns of coarse wire next to the core. Outside this comes a secondary or outer winding composed of very fine wire and having perhaps a thousand times as many turns as the primary winding. (NOTE.—The names of the parts on a model should be taught at this point.) As the armature revolves between the ends of the magnets or in the magnetic field a low-tension current is generated in the primary winding. We call this the primary circuit (primary circuit not useful for ignition), and by *suddenly* stopping this current a strong wave of high-tension current will be "induced" in the outer or secondary winding. This high-tension current is collected by

the collector ring and carried by the collector brush to the distributor where these waves of current, which we call "sparks," are handed out to the right cylinder at the right time.

3. Now, in order *suddenly* to stop or break this primary current it must flow through the interruptor or breaker. This device makes contact for a short time and allows the current to flow through, then quickly separates the contact points, thus breaking the circuit. Now, when a current is flowing through two points, it possesses a certain amount of momentum or speed and when the points are separated it tries to jump the gap and keep flowing a fraction of a second longer in this way. But if it *does* continue to flow we will not have made a quick and complete break in the primary current and the spark will be weak, and this flowing after the points are separated (sparking) will burn away the platinum breaker points, which means that frequent adjusting and filing will be necessary to keep them true. This tendency of the current to keep flowing after the break occurs is taken care of or corrected in the high tension magneto by a device called the condenser, which is capable of temporarily absorbing the current, which would otherwise try to jump between the points when they are separated. When the condenser of a magneto fails, we find the breaker points burning or pitting, and we find the spark becoming weak. An electric current must always make a complete circuit or round trip, returning to the place it starts from. I will now explain the routes of the circuits in the magneto. You will see that we have two complete and separate circuits in a high-tension magneto.

The Primary Circuit.

4. The primary current is generated in the inner or primary winding armature and flows from one end of this winding to the breaker and condenser, from there to ground or frame of the engine and through the frame of the magneto to the core of the armature. The other end of the primary winding is connected or grounded on this core, so in that way the current returns to the place where it started. When the breaker points separate, the current no longer flows through them but is absorbed by the condenser.

The Secondary Circuit.

5. One end of the secondary winding is grounded to the core of the armature. The current is induced in this winding at the time of the break in the primary circuit and flows to the collector ring and through the collector brush, through the connection between the collector brush and the distributor, and from the distributor to the central or insulated electrodes of the spark plug; from there it jumps to the outer or grounded portion of the spark plug through the frame of the motor and magneto back to the core of the armature, completing the circuit. This secondary circuit is of very high pressure, something like 30,000 volts, and must therefore be very heavily insulated. If one of the wires running to the spark plugs should be broken and the ends separated, there would be no outlet for this particular wave of secondary current, and it would jump to the ground through the easiest channel. Usually it would jump through the insulation of the armature, puncturing or ruining the insulation. To avoid this, a safety valve is provided, which is called the "safety spark gap." This is a gap provided on the magneto which has the points separated a great deal farther than the points of the spark plug, but close enough so that the resistance will be less than the resistance of the insulation in the armature. In other words, it will be easier for the spark to jump the safety gap than to jump through the insulation in the armature, but it will be much harder to jump the safety gap than the gap in the spark plugs. Then if we find a spark occurring in this safety gap, that should tell us that the secondary current finds no way to get to ground. These safety gaps are enclosed in fine brass gauze or screen to prevent them from igniting any gasoline vapor which might be present under the hood of the engine.

6. When we wish to stop the magneto we can not use a clutch to disconnect it so it will no longer turn, because when we let the clutch in or connect the magneto up again it would be out of step, or out of time with the motor. The method for stopping the magneto is to "cut out" the breaker. In other words, we take the primary circuit and connect it to the ground before it reaches the breaker. In this way the primary current is

not broken or ruptured by the breaker, and therefore we get pactically no secondary current.

7. In the Bosch high-tension magneto the armature generates two waves of primary current per revolution. It is necessary to have the break in the primary occur at the time when the current is the strongest, and this will mean at the highest point of the two waves I have referred to. In other words, the correct time to have the break occur is when the armature is just leaving the pole pieces on the ends of the magnets. The exact measurement between the armature and pole pieces varies with different magnetos for engines of different number of cylinders, but ordinarily this position of the armature occurs when there is an air space of one-eighth of an inch between the armature and the pole pieces. As airplane motors are run most of the time at full speed there is seldom any necessity for changing the time of the spark, but on some machines the spark is retarded to make the cranking of the motor safer. In all ignition systems, the spark is advanced or retarded by changing the time of the break in the primary circuit. In the high-tension magneto this is accomplished by shifting the cams that operate the breaker. In the Bosch magneto, if the breaker housing that carries these cams is in the fully advanced position, the break will occur with the armature in the ideal position that I have spoken of, but if we retard the spark the break occurs at a time when the armataure has moved away from the pole pieces a considerable distance, perhaps half or three-quarters of an inch. The result is that this type of magneto gives the strongest spark in the full advance position and a weaker spark in the full retarded position. Sometimes the spark in this position is so weak that the motor can not be started on it. It is, therefore, well to start the engine with the spark as far advanced as we can have it without making the motor kick back. Some magnetos overcome this difficulty of having a weak spark in the retarded position by rocking the magnets with the breaker housing, or, in other words, moving the pole pieces at the same time we move the breaker cams, so that the break will occur with the armature in the ideal position anywhere from full advance to full retard. The Eismann, Mea, and Dixie magnetos are of this type. Some magnetos are arranged so that there are four positions of the

armature or rotor, per revolution, in which conditions are right to have the break occur. These magnetos then deliver four sparks per revolution (of the magneto), and such magnetos run at one-half the speed of the other types.

Care of the Magneto.

8. First of all, do not overoil the magneto. Clean oil would not do very much harm in a magneto, but oil as we know it around a motor is never clean. It always contains some carbon or metal particles which make it a fair conductor of electricity, and for this reason it can short-circuit a magneto. Also, if we had oil between the breaker points it would string out when the points separate and supply a path for the current to flow through, thus preventing a quick and complete break in the primary circuit. The breaker mechanism of all magnetos is arranged to run without oil and should not be oiled. The ball bearings on the armature and distributor bearings must be oiled, but only every thousand miles or once a week, and then with a few drops of high-grade, light oil. In cleaning the distributor we sometimes find the contacts or the segments blackened, and it becomes necessary to brighten them up. This should be done with brass polish, pumice-stone powder, whiting, or crocus cloth, but never with sandpaper or emery cloth, no matter how fine they are, because the grit from these cloths would become embedded in the soft insulation material of the distributor and cause scratching or tearing. In many magnetos there are numerous carbon brushes which are apt to become glazed, and when found in such condition they should have the glaze scraped off, leaving them dull. All these carbon brushes have light springs behind them. Never stretch these springs to cause a firmer contact because it is unnecessary, and if the contact is made firmer the carbon brush will wear faster, spreading a streak of carbon powder around the part it touches, and will be likely to short-circuit the magneto in this way. After cleaning the distributor, oil can be rubbed around it with the finger; then the oil should be wiped lightly with a clean rag, leaving only an oily appearance, which is about the right condition. If too much oil is left in the distributor, it will form a paste with the powder

from the carbon brushes and conduct the current from one contact to the next. If the distributor is left too dry, as it would be after washing with gasoline, cutting and tearing would result. If the magneto is driven by a gear direct on the armature shaft, great care must be taken to be sure that the gears mesh properly. If the gears mesh too loosely, they can jerk back and forth and strain the magneto, but if the gears mesh too tightly the bearings on the armature shaft of the magneto will be ruined in a very short time, putting the magneto out of commission. Gear teeth should never "bottom"—that is, the points of the teeth should never touch the bottoms of the spaces in the other gear, but a clearance of from 1/64 to 1/32 of an inch must be left between the gears.

9. When inspecting or cleaning a magneto never remove the end plates which carry the armature bearings, because they are accurately fitted to hold the armature just .002″ from the pole pieces on all sides. Never remove the magnets from the magneto or the armature, because if this is done some of the magnetism or "pull" will be lost from the magnets. These two operations should only be performed by a well-equipped magneto expert. It is not necessary to do these things in the field.

Testing the Magneto.

10. First, suppose we have the magneto on the bench. By taking hold of the magneto shaft where the coupling or gear would go, turn the magneto in its proper direction (usually indicated by an arrow on the magneto). Notice how much pull or resistance it offers as you turn it over. This should feel a good deal like the compression in a motor; and by feeling a magneto in this way which is known to be up to full strength, and then feeling your magneto, you can form an idea as to the condition or strength of the magnets. If the magneto is on the engine and we wish to test it to see if it throws a spark, the best place to test it will be from the collector brush (which collects the secondary current from the armature) and make a spark jump from this brush holder to the frame of the engine by holding a screw driver against the engine and leaning it so it passes close to the brush holder. The magneto should throw

a spark at least an eighth of an inch while the engine is being cranked by hand, but we must remember one important thing. Whenever conditions are right for the magneto to deliver a spark at the collector brush it will also deliver sparks to the spark plugs in the cylinders. This would make the cranking of the motor dangerous; therefore we must either remove all the wires from the spark plugs, which would be quite a job, or the more convenient method is to remove the connection between the collector brush and the distributor, in order to safeguard the man who is cranking. Also remember that the switch must be *open* when we are testing the magneto.

11. If we should fail to find the spark, the first thing to do is to remove the ground wire or short-circuit wire from the magneto, because if there is any defect or short-circuit in the ground wire or in the switch it would have the effect of continually shortening the magneto even when the switch is open. So if we get a spark only after disconnecting the ground wire, we can be sure that the ground wire in some way made contact with the frame of the engine when the switch is open.

12. Let us clearly understand that when the switch is "closed" the primary current from the magneto flows through the switch into the ground or frame of the engine instead of flowing through the breaker of the magneto, and therefore we get no spark in the cylinders, and we say that the motor is safe. When the switch is "open," that means that there is no path for the primary current to flow directly to the ground and it must flow through the breaker. In this way a spark will be delivered. But should our ground wire chafe against some metal part in the airplane so that the wire itself makes actual contact with this metal, the condition would be the same as having the switch closed all the time. If we test the magneto and find no spark, the next thing we should examine after testing our ground wire should be the breaker points. See that they open the correct distance for that particular kind of a magneto. (NOTE.—The Bosch magneto requires .015″ gap between the breaker points; the Berling requires .016″ to .20″, and the Dixie requires .020″.) The breaker points must open the correct gap, no more and no less. Any change in the adjustment of the breaker will cause the break to occur with the

armature a different distance from the pole pieces, and may have considerable effect on the working of the magneto. The breaker points should be clean and smooth. If we find them badly burned we can true them up with a jeweler's file and readjust them so that they open the correct distance or separate the correct distance. However, if they are badly burned, we should endeavor to get another magneto, because the fact that they are burning shows that the condenser is not working properly.

13. I have found by experience that we can tell more about the actual strength of a magneto by the appearance of the spark-plug points than by any other means we have on the field. The correct distance between spark-plug points for Bosch magneto and Dixie magneto is 1/64″ or .015″; for a Berling magneto, .030″. As long as these spark plugs are properly adjusted, if the magneto is up to full strength, the heat of the spark will burn these points to a whitish appearance between the tips, and when the magneto begins to get weak from any cause it will fail to burn the plugs in this manner. Also, if the spark-plug points are too wide apart, this whitish appearance will not be noted. I have found that by carefully watching the spark-plug points I have often been able to remove a magneto which was becoming weak before the engine had missed a shot, in this way *preventing* trouble. Also, suppose that in an eight-cylinder motor seven of our spark plugs show this white appearance between the tips and the eighth does not. If all the plug points are adjusted equally, this will indicate that the insulation in this spark plug is defective, and usually if you will break open such a spark plug you will find a crack in the porcelain which will usually be blackened by smoke. This will prove that you were right in removing the plug.

14. Remember that in ignition work it is the *heat of the spark rather than the size* of the spark which counts. If you are out somewhere with a motor and find that the magneto is becoming weak and have no replacement for it, you can generally cause it to burn the spark-plug points white by closing the points together slightly; for instance, closing them in to .010″; in this way you will be able to keep the magneto in commission for several hours longer, sometimes six or ten hours longer.

Another method of keeping the magneto in commission when it begins to weaken is to retard the breaker housing slightly. This applies to the Bosch and Berling magnetos and will often enable you to get home with a motor or machine. You must not retard the spark too far or overheating of the motor will result.

15. *Remember that magnetos give trouble mostly at high speed, not at low speed*, and when you can get a spark from a magneto by testing it in the manner I have described the motor will usually start well and run all right up to about one-third of its speed, but may not run at all at high speed. In other words, a magneto will *start* a motor unless it is completely "knocked out." When ordering a new magneto it is necessary to state make and type of magneto and number of cylinders on the motor. Also it is necessary to state whether you require a "clockwise" or "anticlockwise" magneto. A magneto is said to revolve "clockwise" or "anticlockwise" as seen when looking at the gear or coupling end of the armature or rotor shaft; this does not refer to the direction of rotation of the distributor.

Timing the Magneto.

16. Timing the magneto consists of three operations: First, we must place the motor or crank shaft in the proper position for the spark to occur; second, we must place the magneto in the position where it is delivering a spark; and, third, we must mesh the gears or connect the coupling.

Placing the Motor.

17. First of all, it is usual to time a magneto for the No. 1 cylinder of a motor. This is not necessary, but it is the conventional practice. Therefore we will place the piston of No. 1 cylinder on the right stroke. Naturally the spark must occur on the compression stroke, the only stroke when there is gas in the cylinder and compressed ready to fire. Now the question is, How shall we know when No. 1 piston is on the compression stroke? If we will turn the engine over in the proper direction or in the direction in which it runs until we see the inlet valve open, we know that we are at the beginning of the suction stroke, and when we see the inlet valve close we will know that the

piston is at the end of the suction stroke and at the beginning of the compression stroke. Now, if we will put a rod or screw driver down through the spark-plug hole on the head of the piston, we can follow the piston as it comes up on the compression stroke and find the top center or highest point of the piston travel. It is best to find this point *accurately* to measure from.

18. Airplane motors are usually timed in full advanced position, because they are seldom retarded. In other words, the advanced position is the most important. Now, the question is, how much advance shall we give this motor, or, how far before top center shall the spark occur? The amount of advance depends on the speed at which the motor runs, also on the type of combustion chamber, whether the motor is of high or low compression, and whether there is one or two spark plugs per cylinder. The faster the motor runs the greater advance we must give the spark or the earlier the spark must occur. If we have a compact combustion chamber, of the valve in the head type, or if we have two sparks per cylinder simultaneously, less time will be required for the flame to travel through the entire charge, and therefore less advance will be required. An experienced motor man can judge fairly closely where the spark should occur on any motor if he knows these conditions. But most men will do well to refer to the instruction book for their particular motor, or to get the information from a superior. Whenever we disassemble a motor or remove a magneto we must make it a point to determine by measurement where the spark occurs, so that we will have this information for that particular motor.

19. As airplane motors seldom have fly wheels the spark timing is generally given in inches of piston travel. Instead of saying the spark should occur so many degrees before top center it is usual to say the spark must occur at a certain fraction of an inch before top center, meaning, for instance, a quarter of an inch before the piston reaches the top of its stroke. Then, to complete the process of placing the motor, suppose our instructions for the motor we are working on are to set the spark 5/16″ before top center. We have already placed our piston at the top center of the compression stroke. We will now take a scale or rule and measure 5/16″ upon our screw driver or rod

and make a mark. Then we will *back* the motor until the piston has gone down this 5/16″. The piston in No. 1 cylinder is now in the correct position and on the *right stroke* for the spark to occur.

Placing the Magneto.

20. We must first decide which distributor contact we will call No. 1. Frequently a figure "1" will appear in a little window in the distributor cover when this contact is made. The breaker breaks once for each contact of the distributor. Turn the magneto until the distributor brush is on No. 1 contact. We will now turn the magneto carefully a few degrees until the breaker points *just begin to separate.* Just as soon as we can see that the points are separating, that is when the spark occurs. Another method is to previously insert a cigarette paper between the breaker points. This kind of paper is only .001″ thick, and when it will slip out it will show us when the points are separated just that amount. That is perhaps the most accurate way to "get the break." We must also be sure that the breaker housing is in the advanced position, because we have no desire ever to make the spark occur earlier than 5/16″ before top center in this particular motor. Now placing the distributor and breaker points we can mesh the gear or connect the coupling. Then our magneto will be timed. Sometimes, when the magneto has been accurately placed, we find that the gears will not *quite* mesh, but require turning in one direction or the other perhaps half a tooth. Many magnetos are provided with adjustable couplings, to take care of such a situation, but if our magneto is not so provided we will have to decide whether we prefer to have the spark occur half a tooth earlier or half a tooth later. If the motor is using a rather large amount of advance, perhaps half a tooth later would be better; and if our motor happens to carry rather little spark advance a half tooth earlier would do no harm. Where two magnetos are used they must be timed exactly alike or "synchronized."

Wiring Up the Magneto.

21. The cylinders receive the sparks in the same order that they get their gas through the inlet valves. When the designer of a motor designs the cam shaft, he arranges it to open the

inlet valves and deliver gas to the cylinders in some certain order. For example, a 4-cylinder engine never fires in numerical order. It will fire either 1–2–4–3 or 1–3–4–2. If it should fire 1–2–3–4 it would have a great amount of vibration and the strains on the crank shaft would be excessive. It is important then for the motor to have a certain firing order to make it run smoothly and also to make it draw gas through the inlet manifold without jerking the gas back and forth or causing it to reciprocate. If the engine fires in the same order in which the inlet valves open, obviously the way to find out the firing order of any motor is to crank it over and note in which order the inlet valves open. For example, we have a six-cylinder motor. We will start with No. 1 cylinder and turn the engine over until No. 1 inlet valve is just opening. Then we will put down the figure 1 on our paper. Now we can turn the motor over a few degrees and see which inlet valve opens next. It may be No. 4. Then the next may be No. 3, 6, 2, and 5. Remember that we must not take for granted that all motors of one make have the same firing order, because some may be right-hand motors and some left (normal or antinormal rotation), and also the manufacturer may have found that he could improve the running of his motor by changing the firing order. The point I want to make clear is this: *Remember the method of finding* the firing order rather than trying to remember the firing order. It is but a few minutes work to turn the motor over and note the actual firing order, and by doing so you will save yourself trouble some time. The magneto delivers the sparks in numerical order, 1, 2, 3, 4, etc., because as the distributor brush moves around it touches one contact after the other, but try to think of the distributor terminals not as No. 1, 2, 3, but as first, second, third, etc.

22. In timing the magneto,. we time it for No. 1 cylinder. So we can connect No. 1 terminal on the distributor to No. 1 spark plug, and the second terminal on the distributor will connect to the second cylinder in the firing order, and the third distributor terminal to the third in the firing order, and so on.

Magneto ____________________	1st	2d	3d	4th
Cylinder Nos ________________	1	4	3	2

23. Above all, in timing a magneto, do not forget to place the engine on the *right stroke.* Before timing the cam shaft, the strokes on the pistons were merely up strokes, and down strokes, but since timing the cam shaft, each stroke has a name, viz, suction stroke, compression stroke, working stroke, and exhaust stroke. The spark must occur near the top of the compression stroke when there is gas in the cylinder and it is compressed ready to fire. This only occurs every alternate time the piston is up. If the spark occurred on the other top center no explosion would occur, as there would be no compression and no gas in the cylinder, and if you should go so far as to start the motor, you would not get so much as a "shot" out of it.

LECTURE VI.

SPARK PLUGS.

1. A spark plug is composed of an outer steel shell, which screws in the cylinder, and a core of insulation material usually made of some form of porcelain with a wire running down the center. This wire is known as the central electrode. The high-pressure current or "spark" from our magneto is delivered to this central electrode and jumps from its inner end to some point arranged on the steel shell of the plug, which, being in contact with the cylinder, is grounded. When mica insulation is used it has a tendency to become oil soaked in time, and with the porcelain insulations there is danger of their cracking from great heat or rapid changes in temperature. The electrodes are usually made of some metal which does not scale easily under high temperatures. The scale would be in the nature of an insulator if it could form. Platinum, iridium, and nickel alloys are generally used for electrodes. The proper adjustment of the gap between the electrodes at the inner end of the spark plugs should be accurately made. Most of the high-tension magnetos require a gap of 1/64″ or .015″, and nearly all modern battery systems require a gap of about .030″, or approximately 1/32″. With high-tension magnetos if the spark

plug points are set too close together the heat of the spark is greater than when the points are far apart. If the spark plug points are too close, the heat of the spark will be sufficient to fuse or melt the tip, and little globules or bubbles of metal are formed on the tips, which are liable to connect or short circuit them, and if the spark-plug points are too far apart it will be difficult for the magneto to throw a spark across them when the engine is running at low speed and the magneto also running at low speed. Because a spark will jump 3/16″ outside the cylinder does not mean that it will jump that far inside. Remember that the spark inside the cylinder occurs while the gas is compressed to 90 or 100 pounds to the square inch and under these conditions can jump only about one-third as far as it can jump outside the cylinder where the air is at atmospheric pressure.

2. I have pointed out that it is the heat of the spark rather than the size of the spark which counts and also that the magneto makes a hotter spark when the points are close than when they are far apart, and there are other arguments in favor of having the plug points close together. If the plug points are far apart, the resistance to the flow of the current will be high and it will not require very much dirt or oil on the surface of the insulation to provide an easier path for the current than jumping the gap. In other words, with the plug points farther apart, the plug will be more easily short-circuited. I have often seen spark plugs with cracked insulation begin to miss at high speed and by taking those plugs and putting the points closer together, thus reducing the resistance at the points, the current would once more jump the gap and the cylinder continue to fire. Under these circumstances, the plug would fire until sufficient carbon accumulated in the crack in the porcelain to provide an easier path for the current than the reduced gap in the plug. It is always best to adjust spark plug points accurately to a gage, because in a multi-cylinder motor the heat of the spark should be uniform in all cylinders.

3. Occasionally we find a motor, or one cylinder of a motor, which floods with oil and continually fouls or short-circuits spark plugs. Under these conditions, a single pointed spark plug should be used, or if you are using a three-point plug in

all the cylinders, break off two of the points in this particular cylinder. The reason for this is that in a three-point plug, while the spark is jumping between a certain pair of points and burning them clean, oil and carbon are accumulating between the points where no spark is occurring. In a single-point plug there is a strong tendency for the spark to keep the points clean, due to its great heat. Also the points should be close together and in this way the current will be able to jump through the oil instead of flowing through it. In spark plugs it is a great problem to carry the heat away from the central electrode fast enough so that this part will not become red hot or incandescent. In some spark plugs the points do become red hot and cause pre-ignition. This will usually show up as follows: You can start your motor on a test block or in a machine and it will run smoothly for two or three or possibly ten or fifteen minutes, and then begin to jerk or jar a little bit. In many cases, it will begin to shake steadily and regularly appearing as execessive vibration. Usually the speed of the motor will be slightly reduced. The thing to do in a case like this is to experiment with some kind of spark plug having shorter and thicker electrodes.

Care of Spark Plugs.

4. When we remove spark plugs for cleaning we should gently scrape the carbon away, being careful not to wedge anything between the shell of the plug and the insulation, because we might crack the insulation in this manner. *Adjust the spark plugs by your gage* and note the appearance of the points. They should be burned whitish in color between the points. If they are not, it probably indicates that the points are set too far apart or that the magneto is weak. If one plug in the set fails to show this whitish appearance it should be replaced, because the insulation is probably defective. If you find small, metallic beads or bubbles on the points they should be adjusted .002″ or .003″ farther apart.

5. It is well to use new spark-plug gaskets frequently. By so doing it will be unnecessary to screw the plug in very tightly and the danger of straining or cracking the insulation by pulling hard on the shell of the plug with your wrench will be greatly

reduced. Never drop spark plugs, because there is danger of cracking the porcelain; and always shake them to see if you hear any rattle in the porcelain. Unfortunately there is often no way in which we can detect the crack in the plug unless it is by noting that the spark fails to burn the points white or that the cylinder misses at high speed. It is an excellent plan to put a few drops of oil on the spark-plug thread before screwing it into the cylinder. If you ever have one stick in a cylinder you will never fail to do this.

LECTURE VII.

INSPECTION OR "PREVENTION" OF TROUBLE.

1. In airplane-motor work if the motor fails the aviator usually fails to accomplish whatever he started out to do. This means that it is important to *prevent* trouble by means of careful planning, thorough inspection, and forethought, rather than to wait until the trouble occurs and then figure out a way to fix it. Inspect in a systematic way. Begin by inspecting the gas feed. To do this, first examine the gas tank and see that there is a good air vent and see that the air vent is not plugged up, because gasoline will not flow from the tank very long unless air can get in to take the place of the gasoline. Next, test the flow from the pipe where it connects with the carburetor. Clean the settlers and strainers in the gasoline line. Clean the carburetor thoroughly, including the jets. Then examine the intake manifolds for air leaks or loose joints. It is important to examine the throttle controls. The best way is to have someone sit in the pilot's seat and operate the throttle, then stand where you can see the carburetor and be sure that when he operates the throttle that it opens all the way and be very sure that when he closes the throttle it closes all the way. This is exceedingly important because it is quite possible to install a new motor or carburetor in a machine and the throttle controls may not fit. The result may be that the throttle will not come anywhere near closing. Then when the mechanic cranks the engine the machine may start ahead so that the propeller will strike him. Next let us inspect the ignition. See that the ground wire or short-circuit wire connections are tight and examine its condition throughout its entire length. See that it does not vibrate or chafe against any metal parts, because after the insulation wears through, the wire will short-circuit against metal parts of the machine, and the effect will be the same as having the switch closed all the time. Sometimes a nail or tack will have been driven through the ground wire accidentally. This will do the same thing. See that the connections of the wire are firm and not likely to work loose, because if they should work loose the pilot will have no way to stop the spark occurring in the cylinders, making it necessary to shut off the gasoline to stop the motor and making it dangerous for the man who cranks the propeller.

2. Examine the switch; see that there are no loose parts. Sometimes trouble will occur from a strand coming loose on a wire where it is attached inside the switch, and these strands may touch the opposite part of the switch and short circuit it. Sometimes the switch will become corroded so that it will not make a contact and the motor will fail to stop when we close the switch, or it might be dangerous to the man cranking the propeller. Always remember that on Bosch and Berling magnetos, and most other makes, when the breaker cap or cover is removed so that you can see the breaker points operate, it will be dangerous to crank the motor, because your contact for short circuiting the magneto is usually in this cap or cover. Therefore, if you wish to crank the motor to see how the breaker points operate, always remove the connection between the distributor and the collector brush or remove the spark plugs. Next we can clean the magneto. First clean the breaker points. The breaker should not be adjusted unless they are considerably wrong, and, if possible, they should be trued up with a jeweler's file when readjusted. The reason is because after the points are adjusted they seldom come together true, and must be squared up with a file. The best policy is to leave the breaker points alone in most cases, but if you find them burned badly or find that they are badly in need of adjustment, it must of

course be done. Clean the distributor; the best way to do this is to wipe it with an oily rag and then wipe off all the superfluous oil with a dry rag, leaving it slightly oily looking. Examine the entire magneto from the outside and see that everything is tight. Next remove the spark plugs. Clean and adjust the points and see if they are receiving the proper strength of spark. See if they are burning white. Be sure to examine the plug for defect or crack in the insulation. Examine the secondary wire, running from the distributor to the spark plugs, and see that they are not chafing against any moving parts, such as the rocker arms or push rods.

2. Remember that these wires carry high-pressure current and any injury to the insulation is likely to cause a leak or short through the frame of the motor. It is well to avoid running these wires close to metal parts, because the rubber in time becomes cracked by the weather, and if we have a foggy morning, making things damp, the current may leak through these cracks and jump to the cylinders or ground. Next we can inspect the valve-operating gear. In high-speed motors all parts of the valve-operating gear *must work freely.* There must be no rubbing or binding. Remember that the valve springs must overcome the inertia of the heavy valves and return them to their seats in an extremely short space of time. When the motor is running fast they must also overcome the inertia from the push rods and rocker arms or other parts of the valve gear and return them to their normal positions. It requires a surprising amount of power to do this, and if there is any excess friction or binding in the valve-operating gear the spring will fail to do it, and inaccurate valve action will result.

3. Cam followers are usually shaped on the end in such a way that they must be held in a certain position to ride the cams properly. Frequently they are held by some form of set screw, and therefore it should be inspected from time to time to see if it is wearing. If a cam follower should turn around it will usually ruin both the cam followers and, what is worse, the cam shaft.

4. The tension of the exhaust valve springs must be correct, or they are liable to become weakened due to their great ten-

sion in some cases, and also due to the fact that they are subject to considerable heat in some motors. In one motor that I know of, if an exhaust pipe gasket blows out, the exhaust flame will come in contact with the exhaust spring, thus drawing the temper from the steel and allowing the spring to collapse. These springs are always tested when the motor is being overhauled, but sometimes they weaken while the motor is in the machine, and can usually be detected by running the motor at its slowest idling speed and listening. The valve with weak springs will usually suck open, or open automatically during the suction stroke and will usually make a buzzing sound as it does this. Sometimes it can be detected by putting the finger on each exhaust valve spring in turn and the one which is sucking off its seat will be vibrating in a peculiar manner. When these exhaust valve springs become weak, air will be drawn through the valves during the suction stroke and will flow into the cylinder and also into the intake manifold and spoil the mixture for all cylinders on that part of the manifold. Its action is very similar to that of a loose joint admitting air in the manifold. On the Curtiss eight-cylinder one hundred horsepower motors a pull-down spring is used for opening the inlet valve. This spring must be at least ten pounds heavier than the intake valve spring or else the valve will not open properly and a "clicking" sound will be heard while the engine is running slowly.

5. Then, next, we should adjust the valve clearance. The designer of engines decides that he wishes his valve to operate with a certain clearance. He designs the cams to give the correct valve timing with this clearance. Then the engineers who test the motor at the factory find what clearance they must give the valves when they are cold, in order to have the correct clearance when they are hot. This clearance is published for all motors, and we should not adjust the clearance on any motor unless we know what the correct clearance is. Having found out what the correct clearance is for our motor, the next important step is to place the motor correctly for adjusting clearance. This must be done for each cylinder in the motor. The best way to do this is to crank the motor in direction of rotation until the inlet valve of the No. 1 cylinder is

just closed, then turn the propeller 90 degrees further. This will place the cam followers on a neutral part of the cam and we can now adjust the clearance. This applies to all four-cycle engines, no matter what the type. Always use a thickness gauge or "feeler" for adjusting these clearances. When you realize that a thousandth of an inch variation in valve clearance may make four or five degrees difference in the timing, you will see the importance of adjusting valve clearance accurately and uniformly.

6. Next, we should try the compression of the motor to see if all the valves are seated properly. The best way to do this is to remove a spark plug from each cylinder. Then put one in one cylinder at a time so that there will be no doubt as to which cylinder is on compression. One good way is to swing the propeller up against the compression hard enough so that the compression will bounce it back again several times, to see how many times it can be done before the air has leaked by the piston or valves enough to let it turn on over freely.

7. Leaky exhaust valves can frequently be heard by listening at the exhaust pipes. Leaky inlet valves can sometimes be heard by listening in the carburetor, but when trying this, have the carburetor or throttle partly open, because many carburetors make a wheezing sound when the throttle is closed.

8. Then examine each part, nut and screw, for tightness. For instance, examine every cylinder nut; then each lock-nut on valve adjustments, and so on, in a systematic way, otherwise the loose ones will be overlooked nine times out of ten. Examine the engine bed bolts to see if they are tight and locked. Examine the water connections. See that there is no chance of the hose sucking shut in the line between the bottom of the radiator and water pump. Examine all copper tubing and brass tubing carrying oil, air, or gasoline; see that they are free from vibration or swinging. See that they are not pinched or likely to be; see that they can not be chafed by any part. For instance, where the pipes run through an aluminum bulkhead in the machine, sometimes a hole is cut small and then the pipe will rub against the edge of the aluminum. In this case, there is danger of the aluminum wearing through the copper pipe in time.

9. Inspect the Tachometer drive. Inspect the propeller. See that it is on tightly and locked securely. The entire power output of the engine is transmitted through the propeller hub, and unless it is very tightly set on the shaft it will " work " or vibrate and it is liable to shear the keys or loosen the hub. This should be very carefully watched. A rapidly revolving propeller has as much ability to do damage as a large charge of dynamite and should certainly be watched.

10. Never " rock " the propeller as a preparation to the pull for starting. Many men are hurt in this way. Place your propeller where you intend to start the pull, raise up on " tip-toes " and start your pull *strongly.* Remember you must pick up a great deal of speed in the first few degrees in order to " carry-over " the spark. As you finish the pull or stroke, manage so that you will be withdrawing your hands. If the motor " kicks back " never try to resist it, simply withdraw your hands instantly. Never have tools in your pockets while cranking, they may fly out of your pockets and be " batted " through your legs by the propeller.

11. The man at the propeller and the man at the switch should " sound off " what they are doing, so there will be no misunderstanding. Make it a rule that the man at the switch will not say " closed " until the switch is closed, because if he should say closed, and then leisurely reach over to close the switch, or make the motor safe, the man at the propeller might work faster and pull the propeller, believing the motor to be safe, and get a severe kick.

Propeller Notes.

A system for diagnosing trouble or " trouble shooting."

1. When a motor is not working right we must first classify our trouble or decide *what the motor is doing.* For example, does it miss, cut out, slow down, back-fire, fail to start, fail to stop, or what? Then, at what speed does the trouble occur? Many troubles show up only at certain speeds, and therefore we should notice at what speed the trouble occurs.

2. Next, if possible, notice what part of the motor is giving trouble. For example, on a " V " type motor, is the right side

missing or the left side? Notice which cylinder is giving the trouble. Knowing which cylinder is giving trouble, we can find the trouble comparatively quickly. Some kinds of trouble can cause the entire motor to give trouble, but could not cause just one cylinder to give trouble. These could be called "general" troubles. Another kind can cause one or two cylinders to miss or give trouble but could not cause a general trouble. These we call "local" troubles.

3. For example, suppose we say our motor is missing. Now, in addition to noticing at what speed the motor is missing, let us note the nature of the miss. For instance, is one cylinder missing occasionally, one cylinder missing steadily, one side of the motor cutting out, or the whole engine cutting out, as it would do if we intermittently pulled the switch? Or is it a scattering miss, which means first one cylinder on one side and then another cylinder on the other side missing, but not regularly? Suppose we decide that we have one cylinder missing occasionally. Some of the likely causes of this trouble would be trouble from oil, slightly cracked porcelain in spark plug, parts binding in the valve action or need of adjustment in the valve clearance; it might be water on the spark plug. Suppose we decide that we have one cylinder missing steadily. This is likely to be caused by one of the secondary wires or leads, running from the distributor to the spark plug, being disconnected at either end; a broken spark plug, or a burned exhaust-valve spring, etc. Suppose we decide that one side of the motor is giving trouble. If this trouble occurs at high speed, it is most likely to be caused by magneto troubles (this can sometimes be remedied by slightly retarding the magneto) or it may be an inlet valve stuck open. If the trouble occurs at low speed, it is pretty sure to be caused by an air leak in the inlet manifold on this side of the engine, a weak exhaust valve spring, which has the same effect, or possibly an exhaust valve held or stuck open.

4. Magnetos will cause one side of a "V" type motor, or every alternate cylinder in a six-cylinder motor, to cut out at high speed, and this is sometimes caused by the breaker points opening a different distance on the two cams; sometimes by the weakening of the magnets, due to vibration or other causes, and sometimes by wear in the armature bearings.

5. Suppose we decide that our motor is "cutting out." Now, this is a "general" trouble and is likely to be caused by some troubles in the *common source* of gas. For instance, in the gas feed, by an obstruction in the spray nozzle or water in the gasoline. Or the trouble may be in the *source* of ignition, *not* in the distributor where the current is handed out to the individual cylinders, but probably in the primary circuit in the magneto. It may be in the secondary circuit, but if it is, the trouble will be between the armature and the distributor.

6. Occasionally an inlet valve stuck open will cause such a violent back-fire as to make the whole motor "cut out," because when a back-fire occurs it burns the gas in the manifold and the other cylinders draw a mixture which is partly burned gas.

7. Now, we may decide that we have a "scattering miss" in our motor. This is harder to find, and frequently we will catch one cylinder in the act of missing and believe we have found a local trouble. This scattering miss is most likely to be caused by a weak magneto, if it occurs at high speed; but it can mean many things. It is usually a combination of several slight disorders. If we find that we have a scattering miss at high speed, perhaps the best thing to do is to examine the spark-plug points to see if they show the proper heat or strength of spark, and if they do not we should put on a new magneto, if possible. If a magneto is not obtainable, we can either close the spark-plug points together a few thousandths of an inch, or, in extreme cases, we may slightly retard the magneto, which will help in some instances. But if we find the appearance of the spark plug such that we may decide the spark is all right, then the best thing is thoroughly to inspect the motor as I have described.

8. To find out which cylinder is missing (if our motor has open exhaust ports or exhaust pipes for each cylinder), the simplest way is to hold a stick in front of each exhaust in turn. In this way, we can readily see when a cylinder misses explosions. Frequently we can watch the appearance of the exhaust as it comes out of the pipe, and at the same instant that we hear the motor miss we may see a slight difference in the exhaust, lighter or darker in one cylinder. This will probably be the cylinder that is missing.

9. When seated in an airplane with a "V" type motor, it is a good plan to listen intently to the sounds coming from the exhaust on one side of the engine at a time. With practice you can concentrate on the sounds coming from one side, and in this way you can tell a great deal more about the operation of the motor than by listening to the entire jumble of sounds.

10. Sometimes when looking at the exhaust of a motor you will see more flame in one cylinder than in another, or different colored flames. This may be an indication of air leaks in the manifold or weak exhaust-valve springs, but it is quite likely to mean that the motor is cold or that the manifolds do not distribute the gas evenly. This is something that a mechanic on the field can not correct. It is well, however, to watch the exhaust of your motor each day and if a change takes place—if, for instance, one side becomes clearer and the other side darker, it may indicate that an air leak has developed or that there is a weak exhaust-valve spring. White smoke is always due to an excessive amount of lubricating oil, but always remember that oil on a plug can be the *cause* of a cylinder missing by fouling the spark plug, or it can be an *effect*. In other words, if a spark plug broke and failed to deliver a spark, oil would accumulate in the cylinder and not be burned, and in this way would be an effect and not a cause.

Troubles and Some of Their Probable Causes.

11. Signs of overheating.

(1) Slowing down.

(2) Radiator steaming. Possibly we notice a smell of burning oil or hot rubber. Frequently as the motor begins to overheat, vibration will increase, making the motor seem to run harshly. Sometimes a smell of too much gas or smell of rich mixture will be noticeable. In any case, stop the motor as soon as you can when this is noted, because continuing to run a motor when it is overheated will usually ruin it. When feeling the motor to see if it is overheated, remember that it must be felt immediately after stopping the engine, because after the motor is allowed to stand a few minutes the outside becomes considerably hotter. The reason for this is that the

water does not circulate when the motor is stopped and becomes highly heated, in turn heating the outer wall of the water jacket and making the motor seem very hot. The radiator, if felt immediately after stopping the motor, will probably feel about "blood warmth" at the bottom and quite hot at the top, but after standing for some time, it may be quite hot all over.

Some of the Causes of Overheating.

12. Some of the causes of overheating are:

I. Obstructed water connections. For example, dirt or rust flakes in the pipes. Or frequently in using hose connections when the pipe is thrust into the hose, the end of the pipe will catch and "curl" the inner layer of fabric back into the hose, in this way at least partially shutting off the water.

II. Broken piston rings. This will cause overheating by allowing the hot gases to pass down between the piston and cylinder walls.

III. Leaky radiator.

IV. Oil in the radiator. This will cause overheating by preventing the water from coming in actual contact with the metal of the radiator, which is cooled by the air. If we take two pieces of iron and heat them to a black heat and put oil on one of them, then drop both of them in a pan of water, we may be able to pick the clean one up immediately, but the one which is oily will remain hot a great deal longer. Therefore, never use an oily measure to fill your radiator.

V. A rich mixture.

VI. Early or late spark. The rich mixture and the late spark cause overheating by causing the maximum temperature to occur late, at a time when there is a great amount of cylinder wall exposed to absorb heat, and therefore this surface will be harder to cool.

VII. Failure of oil pump or oil supply. This causes overheating on account of excessive friction in dry bearings.

VIII. Tight motor or new parts. If the bearings are tight in a motor or there are some tight-fitting parts, the extra friction may cause overheating.

IX. Hot weather. The cooling systems on airplanes are as small and light as possible, and while they serve to cool the motor in reasonable weather, they may give trouble from overheating on exceptionally hot days, simply because the size of the radiator and the amount of water is not sufficient for these extreme conditions.

X. Excessive deposits of carbon or any other cause of preignition will cause overheating.

13. Causes of loss of power:

I. Preignition. Overheating causes loss of power by causing preignition in many cases. Remember that preignition means ignition occurring from some hot parts of the cylinder or hot particles of carbon, and occurs far earlier than the spark would occur, causing a tendency for the motor to work against itself.

II. Tight motor.

III. Bad valve or spark timing.

IV. Broken piston rings.

V. Stoppage in fuel line or carburetor.

VI. Waste of rags in the carburetor. Motors in airplanes draw a large amount of air through the carburetor, and if a bunch of rags were carelessly left under the hood it would easily be sucked up by the carburetor and would be liable to make serious trouble.

VII. Leaky valves or need of overhauling.

VIII. Weak valve springs.

IX. High altitude. When a motor is running in high altitude the atmospheric pressure being very much less than at sea level, the piston will not draw a complete charge. In other words, there is less difference in pressure inside the cylinder and outside, therefore less air will rush in through the carburetor, and the motor never shows as much power in high altitudes as at sea level. This can be partly corrected by opening an auxiliary valve in an effort to increase the amount of air flowing into the cylinders.

Vibration.

14. Some of the causes of vibration are:

I. Preignition.

II. Air leaks in the inlet manifolds. This causes uneven mixture in the different cylinders and therefore a different action in the different cylinders and uneven explosions.

III. Weak valve springs. These cause vibration by admitting air in the same way as the intake manifold leaks.

IV. Broken piston rings. These cause uneven compression.

V. Rare mixture.

VI. The magneto breaker housing may be put on crooked or worn, so that the breaker separates different distances on the two cams, causing uneven spark timing.

VII. The propeller may be out of balance, warped, or "fluttering." If the propeller is built too lightly, it will flutter. This can not be corrected.

VIII. Engine-bed bolts loose.

IX. Engine parts of uneven weight. For example, some pistons heavier than others. These parts must be as nearly as possible the same weight, usually within one-quarter of an ounce.

Loss of Compression.

15. Some of the causes are:

I. Valve held open, or no clearance.

II. Leaky valves or valves needing grinding. Sometimes the valves have chunks of carbon holding them off their seats.

III. Scored cylinders.

IV. Cracked pistons or cylinders.

V. Worn or broken piston rings.

VI. Cylinder dry or out of oil. For example, if our motor has been standing in the storeroom without being run, all the oil may drain off the pistons and cylinders, leaving them comparatively dry, and poor compression will result. Sometimes in priming a motor with gasoline on a cold morning we will get an excess of gasoline in the cylinder and wash the lubrication out of it. In either case the remedy is to put in some extra oil through the spark-plug hole.

VII. Loose spark plug or bad spark-plug gasket.

Failure to Throttle Down, or Stopping When Throttled.

16. Some of the causes are:

I. Throttle may be stuck or shifted in the carburetor.

II. Throttle controls may be adjusted wrong, not allowing the carburetor throttle to close.

III. Very bad air leaks in manifold or weak exhaust valve springs. In these cases the excessive amount of air leaking in will either stop the motor when it is throttled down or cause it to idle too fast. The latter trouble would be in case the mixture had been too rich. Then the excess of air would thin this mixture down and make more of it. The result would be the motor would idle too fast. The best way to find air leaks in the inlet manifold is to run the motor throttled and put oil on each point with oil can. It will be sucked in where the leak is. *Don't use gasoline*, because there is danger of fire from the exhaust. It is possible to get enough suction for this test by closing the throttle and turning the motor over by hand.

IV. Spark plug points may be much too wide apart. In this case it is difficult for the magneto to throw a spark across the points at low speed.

V. Throttle closed too far. Nearly all carburetors have an adjustment to limit the closing of the throttle, usually on the throttle arm.

VI. Too much or too little gas, or, in other words, imperfect low-speed gas adjustment.

VII. Auxiliary air valve may be loose or stuck open.

Back-Firing.

17. A back-fire is caused either by the inlet valve being held open, spark occurring while the valve is open, or by a rare mixture.

18. Let us take these causes one at a time and reason them out.

If the inlet valve is held open, that might be caused by lack of clearance, cam followers stuck, or valve stuck open. If the spark is occurring while the inlet valve is open it might be caused by the magneto being timed wrong, the valve timed wrong, or the magneto leads (secondary wires) being crossed or connected to wrong cylinder. If the back-fire is caused by a rare mixture, *remember that the rare mixture may be from either too much air or not enough gas.* If it is too much air the auxiliary air valve may be stuck open or the spring may be weak. You might have air leaks in the inlet manifold or weak exhaust valve springs admitting air. If the motor is not getting enough gas, this might be due to a clogged air vent in the gas tank, water in the gasoline pipe or in the jets. It might mean that the motor was cold or that hot air was needed.

Loud Exhaust.

19. If the motor is making a loud exhaust, the question is, What can cause it? The noise that we call the exhaust is pressure escaping through the exhaust valve when it opens. An unusually loud exhaust means there is an unusual amount of pressure at the time the valve opens. This might be caused by the valve opening while there is high pressure; that would mean opening early. The valve might be stuck open; a cam follower turned around; or, if all the cylinders are making a loud exhaust, it might be the cam shaft is out of time.

20. Now, the other way to think of it is that there may be high pressure at the time the valve opens normally. This might be caused by a rich, slow-burning mixture, or from a float valve being held open by dirt. Possibly the rich mixture could be caused by the tube through which the carburetor sucks the warm air being sucked shut. A late spark can cause a loud exhaust by causing the maximum pressure to occur late in the same way that the rich mixture would cause it.

21. If all cylinders make a loud exhaust, it may mean that the magneto is timed wrong. Sometimes a loud exhaust in one or two cylinders may be caused by the magneto leads or spark-plug wires being crossed or mixed up.

Failure to Start.

22. If the motor fails to start, the first thing to do is to inspect the gas feed carefully. Prove that the gas flows through the passage where it joins the carburetor, and prove that it flows through the jets by running a wire through them. If the trouble is not found then, test the magneto by "grounding" a screw driver against a cylinder. Place it close to the top of the collector brush or any place where we can get at the secondary

current before it reaches the distributor to see if we get a spark. If we fail to get a spark, remove the ground wire and try it again. If we still get no spark, thoroughly inspect the magneto, and if no spark can be obtained we must have a new magneto, or at least a magneto expert.

23. If the magneto tests out all right, the next most likely cause of failure to start would be that the motor is "flooded," or, in other words, in trying to start we may have drawn so much gasoline into the cylinders that it can not burn. In this case we must shut off the gasoline and close the switch, open the throttle, and endeavor to get a charge of clean air into the cylinders, or, in other words, "air the motor out."

24. If the motor has been flooded, it will probably start under these conditions. If we have found all these things all right, then the trouble must be that either the spark or valve timing is incorrect. In that case check the spark timing; turn the engine over until the inlet valve on one cylinder has just closed; remove the spark plug and insert a screw driver or wire and follow the piston up to the top of the stroke; *back* it down from one-quarter to one-half an inch. Now, by following the spark-plug wire of that cylinder to the distributor we should find the distributor brush touching the contact to which this wire is connected.

25. If this is correct, the spark timing is not at fault, because if the magneto was timed close enough so that we would find the distributor in contact by this method, it would be near enough for the motor to start, or at least for it to "kick" one way or he other, certainly on the right stroke. If we have time, we can measure the magneto timing more accurately to see if the amount of advance is correct, but it is seldom that we find any great mistake in the amount of the magneto advance, while we often find the magneto firing on the wrong stroke.

26. If the valve timing is suspected, it is only necessary to turn the engine over and find out by watching the exhaust valve, and by putting a rod through the spark-plug hole, *where* the exhaust valve closes. The exhaust valve must close on or slightly after the top center.

Failure to Stop.

27. Sometimes when we close the switch the motor keeps on running or "kicking." If it merely continues to kick, the chances are that the motor is hot, or overheated. Possibly some particles of carbon, spark-plug points, or exhaust valve remain red-hot (or incandescent) and are igniting the charges. If the motor continues to run smoothly after we close the switch it is likely that the ground wire has become disconnected or the switch fails to make contact. Possibly the breaker cap or cover is off and not making contact. Sometimes the breaker housing is not put on far enough. In this way the breaker cover is held away from the breaker, so that it can not short circuit it.

LECTURE IX.

INSTALLATION, CARE, REMOVAL, AND STORAGE OF MOTOR.

1. In placing a rope around the motor preparatory to raising it for installation in the fuselage, be careful to keep the rope away from any part it might injure. The water jackets on airplane engines are usually delicate, and the rope must not press against them. Priming cocks are easily broken off. Rocker arms are likely to be bent, and small copper or brass tubing could be smashed flat by a rope. The timbers or beds on which the motor will be placed in the airplane must be level and parallel, and the bolts holding them in the machine must be tight.

2. After the motor is placed in the machine, the switch and ground wire should be connected up *first*, so that the motor may be made "safe" while the propeller is being installed. In making up the water connections, be careful that the ends of pipes do not "turn in" the inner layer of fabric in the hose, thus obstructing the flow of water. If tape is used on these water joints, it must be shellacked afterwards, because if the

tape is not coated with shellac it will unwrap and deteriorate from the effects of the hot weather. Make it a rule never to connect the gasoline to the carburetor without first allowing gasoline to flow through the pipe for the purpose of flushing or cleaning the pipe and also to prove the flow of gasoline.

3. Check the adjustment of throttle and spark retard wires or rods to see that they are properly adjusted to the motor. The throttle must open fully and close fully, and when the magneto is pulled to the retard position, be sure to see that the spring will pull back into the full advance position, because if it fails to do this, the motor will probably overheat.

Testing the Motor on a Testing Block.

4. Airplane motors are tested after overhauling before being installed in an airplane.

5. Around flying fields we seldom have opportunity to test a motor for horsepower output, but generally put a standard propeller on the motor or a " club " (dummy) propeller which will turn at the same speed as the propeller. If the motor turns this standard propeller or " club " to the required number of revolutions its power output is considered satisfactory.

6. While running on the block with this propeller or " club " the motor must:

A.—Run up to specified revolutions.

B.—Throttle down and pick up smoothly when the throttle is opened.

C.—Not accumulate oil in the cylinders or foul spark plugs.

D.—Reveal a proper oil-pressure for that particular motor, so that it will not throw oil. The motor must cool properly and *not have excessive vibration.* Must not slow down after running half an hour or so, or seem to meet very accurate adjustment, and must not be " sensitive." Compression must be even and motor must turn freely.

Care of the Motor.

7. To give you some idea of how an airplane motor is cared for, I will tell what is done to one make of motor used to considerable extent in the Government schools.

8. The motor receives a thorough and careful inspection and cleaning daily. After each five hours' running the valve clearance is carefully adjusted to a gauge, spark plugs are removed, inspected, and adjusted. All the oil is removed from the oil pump and renewed after fifteen hours' running. This is because the oil comes in contact with the hot piston heads and deteriorates from the heat; also becomes filled with chunks of carbon and a certain amount of liquid fuel condenses in the cylinder and mixes with the cylinder oil, impairing its lubricating qualities. Remember that if a motor is run too long without overhauling, when it is finally removed from a machine it will require an expensive rebuilding instead of overhauling.

Removal of Motor.

9. Make it a rule to remove the *propeller first* and *ground wire connections last*. This is so that the motor may be made "safe" as long as the propeller is on it. Be sure that everything is disconnected before raising the motor with the "chain" fall or tackle.

Storage.

10. While the motor is in storage be sure there is no gas left in the carburetor. If gas is left in the float chamber of the carburetor it will evaporate and leave a deposit of some kind that is likely to clog the gas passages when the engine is used again. Oil should be put in the cylinders through the spark-plug holes and the motor turned over by hand a few times, at least each week, to prevent rust in the cylinders, and the valve stems should be oiled with an oil can.

Overhauling.

11. Overhauling is a very elastic word. It can mean merely disassembly and reassembly of a motor, or it can mean very carefully taking a motor apart and noticing each place where it is wearing or rubbing and investigating the cause, and careful planning to correct and improve conditions while assembling the motor.

12. One important thing is to trace the lubrication system from the oil pump or through the motor and back to the sump. After learning the route through which it travels all passages should be carefully cleaned out by forcing gasoline through them to avoid any possibility of stoppage in the oil circulation.

13. After a motor is overhauled it is best to make two or three short flights, for instance, 10 or 15 minute flights, before a long flight is made, and the motor should be examined or felt after each of these short flights. It is far better, if possible, to install the motor on a block and test it thoroughly before installing it in an airplane.

LECTURE X.

DIFFERENCES BETWEEN AIRPLANE AND AUTOMOBILE ENGINES.

1. First of all, airplane engines are always built lightly and this means that the crank case is not very rigid. The timbers or beds on which the engine sits must be carefully lined up and be perfectly true so that the crank case will not be sprung out of shape when it is bolted to them.

2. Airplane engines run at nearly full capacity all the time. This means that we have full compression, maximum temperatures, and maximum pressures, also maximum vibration all the while. Lubrication of moving parts becomes a greater problem under these conditions. For example, in a racing automobile the driver throttles down his motor to a certain extent on the turns. This will allow the crank shaft to ease up on its bearings slightly, allowing the oil film to be renewed under the shaft. In the airplane motor there is no such easing up on turns. Airplane engines run at high temperatures because of the necessarily light weight of the cooling systems. In other words, the cooling systems are very close to the limit. Airplane motors are subject to strains caused by the propeller. Even the best built airplane propellers vibrate or flutter to a certain extent and all this vibration goes through the motor. Usually the

crank shaft gets it first, and when flying the gusty winds impose great strains on the propeller and crank shaft due to the uneven air through which the propeller is working. As the airplane is "pushed" or "lead" through the air by its crank shaft in most cases, it is necessary to have a substantial thrust bearing on the crank shaft to take care of these strains.

3. It is somewhat difficult to tune up an airplane motor on the ground for the following reasons: The motor can not be run long on the ground without overheating because the airplane is stationary and the propeller throws little or no air through the radiator. (The central part of the propeller is not designed to do any work or throw any air to amount to anything, and the result is that it throws practically no air through the radiator when the machine is standing still.) The result is, if we are tuning up the motor, we can run it with throttle open for short intervals.

4. In some machines there is a difference in the atmospheric conditions around the carburetor when the machine is standing or flying. For instance, when the machine is flying, there may be either a decrease or an increse in the atmospheric pressure, due to the location of the carburetor, and this makes carburetor adjustment on the ground difficult in some instances.

5. Airplane engines must run at high altitudes and under these conditions encounter very low temperatures and very low atmospheric pressure, which means that the cylinders will not get a complete charge of gas. A motor loses a large percentage of its power, even at a 10,000-foot altitude. The reason is that there is less air pressure outside the motor; therefore less air or mixture rushing through the carburetor and into the cylinder during the suction stroke. One of the remedies for this is to open an extra air passage in the inlet manifold to allow a larger volume of air to enter the cylinders. Other methods are being experimented with.

6. Airplane engines must run at all angles. This means there must be plenty of "fall" from the gasoline tank to the carburetor. The oil sumps of the crank case must have the oil continually pumped out of them because a large accumulation of oil in the crank case would flood the cylinders under certain flying conditions. Some of the exhibition flyers have

had carburetors especially arranged to feed gasoline while the airplane is upside down. Such devices are not in common use, however.

7. You probably know that if we take "hay-wire" or soft iron wire and bend it several times it becomes brittle and breaks. This is known as crystallization. In airplanes, if the engine vibrates, it sends little strains through the entire airplane which bend the metal parts ever so slightly. As these vibrations occur frequently and for long periods, we find the metal in time becomes crystallized in the same way as the soft iron wire I spoke of. The result may be that while the machine is "taxying" along on the ground to the hangar, fittings may snap simply because they are crystallized. I mention this so that you will know the importance of keeping a motor running smoothly. On an airplane motor the compression in all cylinders must be uniform. Moving parts must all weigh alike. Spring tension must be uniform. Spark plug points must be adjusted at uniform gaps. If more than one magneto is used, they must be carefully synchronized or timed together and certainly all the plugs must be of the same make and type.

8. Airplane engines must be free from vibration, because engine vibration rapidly crystallizes all the metal parts in the airplane, which means that they are liable to break without being subjected to any great strains.

9. Most American airplane engines are built with the carburetor very low. While this gives a long inlet manifold which has some disadvantages, it has the advantage of placing the carburetor where it is easily fed from a tank located in the fuselage of the airplane. Many European machines have a gas tank placed in or under the top plane, but this necessitates pipes running up to this tank and consequently increased danger from leaks and possible fire.

10. A good many air-pressure, gas-feed systems are used with good success, and also gasoline pumps pumping an excessive amount of gasoline to a tank which will feed the carburetor by gravity. This tank has an overflow pipe to the main storage tank to take care of the excess delivered by the pump. Remember that gasoline tanks in airplanes must have "baffle

plates" to keep the gasoline from washing from one end to the other. One reason for this is that if gasoline *could* rush from one end to the other it might seriously affect the balance of the airplane. Air vents in gasoline tanks must be so arranged that should gasoline splash out of them it could not be ignited by the hot gases from the exhaust pipes. Frequently these vents have a tube running down through the bottom of the fuselage for safety.

11. Up to the present time most airplane motors have been equipped with exhaust "stacks" (short pipes). The purpose of these stacks is to carry the gases away from the fuselage, and also to have a slight syphon effect to scavenge the cylinders, but at present many airplanes are equipped with pipes to carry the exhaust gases and sounds above the upper plane.

12. It is difficult to use mufflers on airplane engines, partly due to the fact that a muffler reduces the power of a motor, but more particularly because an engine is more difficult to cool if it is equipped with a muffler and the exhaust is more liable to burn.

13. The gaskets between the exhaust pipes and cylinders are important. If they blow out, there is danger of the flame coming through and burning some part of the airplane, or in some motors this flame could ruin the exhaust-valve springs by overheating them and causing them to collapse.

14. Gasoline strainers and settlers must be arranged so that they will work properly with the airplane in various angles. Many settlers now in use fail in this respect.

Back-firing.

15. Back-firing in the carburetor is particularly dangerous in airplanes. Some manufacturers are experimenting with devices to prevent back-firing. If an airplane catches fire, it is a very dangerous situation for the pilot, because he can not step out on the ground and use the fire extinguisher. If he is up in the air, he is likely to be burned badly before he can land the machine, therefore every precaution should be taken to avoid chance of fire.

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